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AN ANALYTICAL FRAMEWORK FOR DETERMINING LIFE CYCLE COST IMPLICATIONS OF THE ADVANCED LAUNCH SYSTEM

THESIS

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THESIS

Presented to the Faculty of the School of Engineering
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Air University
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Master of Science in Operations Research

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Preface

This thesis developed a life cycle costing model for the Advanced Launch System using a spreadsheet software package. The new model provides the analyst with a method of performing quick cost analysis and graphics output to support key decision makers. Though the thesis modeled the Advanced Launch System, the technique and model environment are applicable to other developing systems

During the development of this thesis effort, I received outstanding support from several individuals and organizations. I wish to thank my thesis advisor, Lt Col James Robinson for his insight and support during this effort. I would like to thank Dr Cain, my reader, and Dr Kanke, Logistics school instructor for providing me with an excellent background in cost analysis. I received outstanding support from my sponsors at the Air Force Astronautics Laboratory (AFAL) and at Air Force Space Division (AF/SD). Capt David Rosenburg, AF/SD, provided key information on the Advanced Launch System and current modeling methods that was essential to this effort. Mr Dave Perkins, senior analyst at the AFAL, served as a sounding board and sanity check for the ideas presented within this effort.

Last, but definitely not least, I would like to thank my wif[redacted] sons,[redacted] for their support on my second thesis in less than three years.

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Abstract

The product of this research effort was a simplified cost analysis tool that can be used to determine life-cycle-costs for the Advanced Launch System. The major objective was to develop a tool that would allow quick analysis of proposals and provide data input in a timely fashion. The work was co-sponsored by the Advanced Launch System program office and the Air Force Rocket Propulsion Laboratory.

This effort produced a core program that can be used to determine life-cycle-costs as a function of system components, production infrastructures, reliability assumptions and flexible mission models. The life cycle cost model can operate in either a deterministic or stochastic mode depending on user inputs. An additional effort modeled the production infrastructure using a network flow system. This system modeled the flow of the basic vehicle components from initial production through final launch.

The analysis tool uses ~~utilizes~~ a commercially available spreadsheet package available for most personal computers. The analyst using this program operates in a user-friendly environment that simplifies data input and problem formulation. The user has a wide variety of output formats and graphics options that simplify report generation.

AN ANALYTICAL FRAMEWORK OF DETERMINING LIFE-CYCLE-COST IMPLICATIONS OF THE ADVANCED LAUNCH SYSTEM

I. INTRODUCTION

Need For Launch Capability

Prior to January 28, 1986, the United States had made a commitment to the Space Transportation System (STS) (14). The STS, using its four shuttles, was to become the primary means for placing payloads into orbit. The Air Force was not totally in agreement with this concept and was able to convince Congress to allow the purchase of several Titan expendable launch vehicles to supplement the Air Force's share of the future shuttle capabilities. This proved to be a fortunate move for the Air Force, when on January 28, 1986, the Challenger exploded and took with it most of the nation's launch capability. The Air Force immediately increased the order for expendable launch vehicles. Unfortunately, within a short time of the shuttle disaster, two Titan expendable launch vehicles also failed.

The Air Force quickly went to work to improve its launch capabilities. First, a Titan recovery program was initiated to review the Titan accidents and make needed changes. Part of this program was to look at improvements to increase reliability and payload capability. These efforts resulted in a relatively quick resolution of the design problems leading to the failures and return of the Titan to active status. It also resulted in several new technology development programs that would offer increased Titan payload and reliability.

At the same time the Air Force was fixing its Titan problems, studies were started to look at the entire US space program and to determine vehicle requirements to carry Department of Defense (DoD) payloads through the end of the century. The largest of these studies was the Space Transportation Architecture Study (18). It was a $20 million 26-month effort split among four contractors. The objectives of the study were to determine overall space transportation architectures and transportation systems that perform DoD and NASA missions in a cost effective manner. Other objectives were to identify enabling technologies and to study the impact of ground and space operations. This study considered many alternatives, but focused in on the question of reusable systems vs. expendable vehicles.

Shortly thereafter, a series of studies was funded by the Air Force Astronautics Laboratory (AFAL) to look at low-cost expendable propulsion (18). These studies looked at various systems and how they might meet near-term launch requirements. All indicated that an expendable system would be the cheapest near-term solution to solve the Air Force payload problems. This conclusion was based on trade-off studies that compared development, procurement and operations costs as a function of near-term attainable reliability for a low launch rate mission model. An additional incentive for the Air Force was the possible deployment of the Strategic Defense Initiative (SDI) system (7). Early estimates predicted this system might require the capability to place up to five million pounds per year into low-earth-orbit (LEO) for ten years. In order for SDI to be cost effective, the cost per pound would have to be reduced drastically from the current cost of three to four thousand dollars per pound.

These efforts provided a quick transition to the concept of the Advanced Launch System (ALS) whose office is located at Space Division at Los Angeles Air Force Base (SD/ALS) (20). Though originally called other names such as the Complementary Expendable Launch system, the Medium Lift Launch Vehicle or the Heavy Lift Vehicle,

the ALS program was officially created in April 1987. ALS will be a joint program developed by NASA and the Air Force. The major drivers behind ALS will be high reliability and reduced launch costs. Lt Gen Abrahmson, Director of the SDI office, has predicted that launch costs will have to be reduced by almost an order of magnitude. The new launch system will have to have high reliability, high performance margins, reduced operations and maintenance costs, reduced acquisition costs and payload flexibility (7).

Reliability for ALS is a major area of concern. The decision concerning an expendable versus a reusable vehicle for ALS comes down to one of cost. The determination of the cost is directly based on system reliability. Expendable systems use cheaper vehicles for each flight, but the vehicle is lost each time it is used. The reusable vehicle on the other hand is much more expensive, but in theory has a much longer service life so the cost per flight is less (10). If the reusable vehicle suffers a higher than expected failure rate the cost per flight may be many times higher than the expendable system. The shuttle for instance assumed a reliability of 99.9% or one failure per thousand flights. In reality, the first failure came on the twenty-fifth flight for a reliability rate of 96% based on the current number of launches. Failures of these types both in manned and unmanned systems have shown that reliability rates have been historically lower than initial predictions. Therefore, decisions on new vehicles need to include sensitivity studies looking at the impact of realistic reliability rates as they impact mission costs and capability.

Another major area of space operations concerns the infrastructure that surrounds the total launch operation (21). Infrastructure refers to the total system required to design, manufacture, assemble, launch, operate and recover space vehicles. The current system is a complex collection of personnel and facilities that has evolved in a rather unplanned and inefficient manner. It is a large system that represents a

major overhead cost that must be applied to all launch vehicles. Not since the beginnings of the shuttle program has NASA or the Air Force had the opportunity or funds to consider a totally new concept for launch operations. ALS will take a clean sheet approach and attempt to design and build a new launch system infrastructure that will operate in an economical and efficient manner. This would include new production and assembly facilities that would reduce costs, increase quality control and be located near the launch site.

The management and analysis of the ALS effort places a large work load on the analysis personnel (7). They have the responsibility of performing independent analysis on the contractor designs and performance data. This type of work requires experienced engineers and cost analysts. Often these studies take several weeks and require large amounts of computer resources and personnel. Due to the fast pace of the program, results are needed quickly and often the analysts lack the time to develop new tools that might shed light on the problem.

Problem Statement

This thesis effort addresses the problem of how to perform quick life cycle cost (LCC) analysis. The ALS office receives large amounts of contractor data on prospective systems. They are tasked with having to quickly analyze this data in order to make key program decisions. The analysis does not need to be detailed, but does need to include key elements of each system that will have the major impact on the total LCC. Current methods often require on-site contractor support or highly trained cost and systems engineering personnel to analyze the data.

The high cost of delivering payloads to orbit requires careful analysis of all proposed launch systems. Major reductions in the cost of placing payloads in orbit will have to be made if large payload intensive systems such as the proposed space-based

Strategic Defense Initiative concept are to be deployed. The need for these studies in a short period of time drives the requirement to build an analysis tool that will provide data to decision makers (21). Key decisions that have to be made concern:

--the choice of launch vehicles and their respective costs,

--the cost impact of production and assembly facilities location relative to the launch facility,

--the level of required reliability to reduce costs,

--the types of payloads and mission models that the new system will service.

These factors are all be constrained by the funding environment, the relationship between the Air Force and NASA, levels of technological advancement, attainable levels of operation, competition from non-DoD launch services and interactions with the launch vehicle community.

Many of the past tools used were difficult to learn and often required a large investment of manpower and computer resources. This indicated the need for a tool that would run on a desk top computer with user friendly characteristics. The new tool should be relatively easy to learn so that program managers can perform needed analysis without the full time support of outside cost experts or contractor personnel. A complaint concerning previous analysis tools and methods was the requirement to use programming languages such as Fortran or Pascal that everyone was not trained to use (10). This created the requirement that the new tool should use software that was easy to learn, but still had excellent analytical capabilities. The new tool should be created in such a manner that it may be modified to handle new scenarios and new launch systems. These changes should not require extensive programming capabilities on the part of the analyst. A final problem was the presentation of the final output. Most of the results had to be presented either in technical reports or

briefings. This required extra time to take the study results and place them in a usable format for presentation. The new tool should provide some sort of presentation quality output.

Research Scope

The scope of this thesis effort is limited to building a prototype life-cycle-cost (LCC) model for the ALS program office and the Air Force Astronautics Laboratory. This effort is the beginning step of a multi-thesis effort to provide ALS as well as others with an advanced life cycle cost model to use for analysis. It addresses the issues of life cycle cost as it relates to system components, production techniques, launch facilities, reliability and mission models.

A life cycle cost model is developed that will enable the ALS and AFAL personnel to analyze and determine the impact of new technologies, production methods and mission models on the ALS and its life cycle cost. The model breaks the total costs down into four main areas: research and development investment, production, operations and unreliability. Costs for these areas are determined using cost estimating relationships based on past cost data and estimates of future costing trends. The major scope involves the ALS cost model development and creation of test cases to validate the concept. The data used in this effort is kept unclassified, but provides realistic results to help validate the research effort. The test cases look at the effect of varying mission models, production facilities, reliability and system capabilities.

Methodology

The first step in this effort was a thorough literature review and in-depth interview process with key organizations. The key personnel contacted were the ALS cost estimating section (SD/CLHS) and the space analysis group (AFAL/VSB) at the

AFAL. Both groups are heavily involved in the development of ALS. Contact was made with the Air Force Studies and Analysis Command, Control and Reconnaissance division (AFSA/SASC). This group is concerned with the support necessary to provide launch for the satellite and other space assets. Phone interviews were made with the Office of the Secretary of Defense, Program Analysis and Evaluation (OSD/PA&E). This group provides cost analysis support and program recommendations on major system developments to the Secretary of Defense. These groups provided insight into current programs and methodologies concerning LCC techniques. The results of the interviews and literature search are presented in detail in the next chapter.

Once the requirements were determined, work began on the prototype model. The first major task was to choose an environment in which to build the tool. The choice was made to use a spreadsheet based on requirements and desired model characteristics. The analysis techniques to be used in the model were derived from traditional costing theory, existing codes and past studies. Guidance for this phase of the effort was provided from modeling experts at the ALS office and at the AFAL. The details of this process and of the model will be presented later in the study.

After the model was built and verified, a small analysis effort was performed. This effort looks at the impact of system reliability, production techniques and development costs on LCC as a function of the mission model and the related infrastructure. Data for this effort is unclassified and coordinated through the ALS Joint Program Office (JPO).

Assumptions

In order to scale down the problem to a manageable size, many assumptions and decisions were made. The code models a generic launch system that resembles several of the proposed ALS vehicles, but does not duplicate any one vehicle exactly nor use

classified data. The analysis is done solely to demonstrate various capabilities of the code, not to propose a best launch system. An inherent assumption is that the reader has a basic understanding of personal computers and the spreadsheet environment. Reference sources are cited so that the reader may acquire more detailed information if needed. This effort's main purpose is to demonstrate a flexible technique to do LCC analysis using a spreadsheet environment. Therefore, the model shown is only an example of one possible analysis task. Modifications will have to be made to analyze other vehicles and other scenarios. However, this analysis environment is flexible and relatively easy to reconfigure to allow study of numerous systems.

Thesis Overview

Having presented the study objectives and methodology, the remaining chapters present detailed background data, explain the models and present a representative analysis using the model. Chapter Two presents a picture of the events that lead to the development of the ALS program and related studies that provide insight into the program. Information concerning some recent cost modeling efforts is also presented.

Chapter Three presents the details of the life cycle cost (LCC) model. The LCC model provides the user with a cost estimate based on key input parameters. The main areas that will be covered include research and development, production, operations and unreliability. All costs attributed to ALS are placed in one of these four categories. The costs generated by these four areas are then summed to form the total LCC. This section provides several methods of defining LCC and explains the rationale and methodology for each definition. The chapter describes the initial deterministic model and then demonstrates how to modify it to perform stochastic analysis.

Chapter Four present the infrastructure model. The previous LCC model assumes that the production infrastructure can provide all the vehicles and launches as needed. This infrastructure model looks at the actual capacity of the production system. Using network flow theory, the production system is modeled based on proposed ALS systems. This model then determines the expected production and number of possible launches based on user inputs. The production output and resulting feasible launch rate can then be compared to the number of required vehicles per year assumed in the previous LCC model. This allows the analyst to verify that a proposed production system has sufficient capacity to meet an aggressive launch schedule.

Chapter Five presents a series of analysis results showing the possible uses of the model. This sample analysis efforts demonstrate the use of the model in both the deterministic and stochastic forms. Chapter Six presents the conclusions and recommendations of the entire model development effort. Printouts of the spreadsheet models are located in the Appendix section for detailed study.

II. Background

Recent Space Activity

The need for a new cost effective launch system can be better understood by examining the past history of launches. Figure 1. provides a look at historical trends of launch costs dating back to the early 1960s (6). The early flights placed small payloads into low-earth-obit (LEO) at costs exceeding $10,000 per pound. This cost was steadily reduced as the vehicle technology matured and the launch rates increased. An extrapolation of this cost trend shows that costs will remain well above the ALS goal of $300 per pound based on existing technologies and utilization rates. The shuttle rates shown are for 12 and 24 flights per year for the entire fleet.

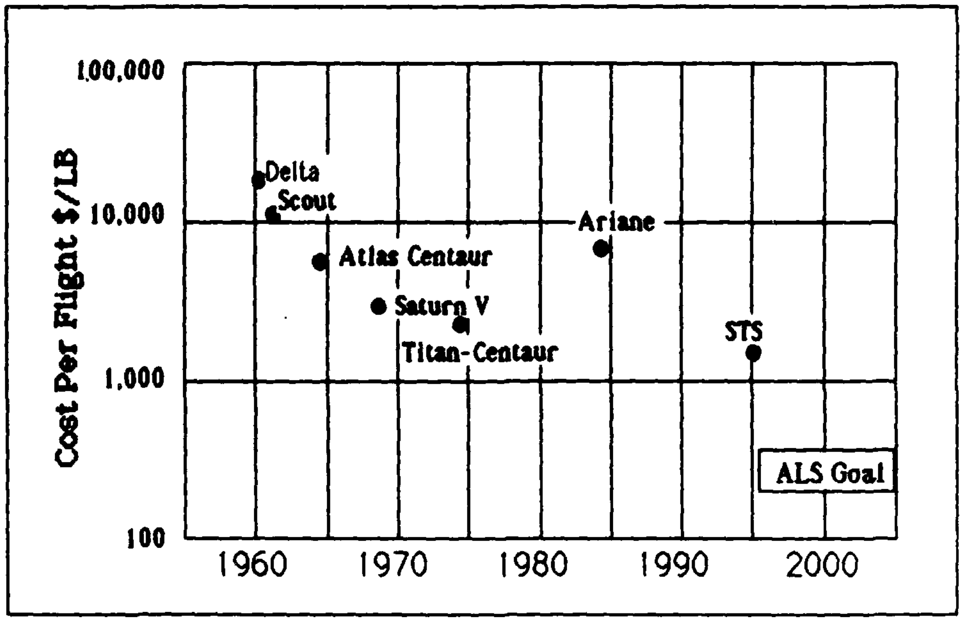

Figure 1. Historical Costs for Past Launch Systems

A pre-ALS study (1) suggests that current technologies coupled with high launch rates (100 flights per year) and large LEO payloads (250,000 lbs) would bring flight costs down to the $500 per pound range. However, these flight rates are unrealistic considering the current small number of expected launches. For instance, the shuttle will only fly 6-9 times per year in the near future and the Titan at full production will not fly more than once per month (19). Also, the high cost of satellites ($5000-$10,000 per pound) would present the possibility of multi-billion dollar losses if the suggested 250,000 lb capability were regularly utilized. Current payloads range from one to two satellites weighing well under 35,000 lbs each. The problems associated with this type of proposed design indicate that the ALS must prove cost effective using realistic mission models (small launch rates) while delivering normal payloads.

A decision made several years ago to reduce costs has had a major impact on the current Air Force launch capability (3). In the late 1970s a decision was made to use the shuttle as the sole launch vehicle for US space assets. This decision was made based on the belief that the shuttle performance would increase, the launch rates would increase to 24 per year and it would therefore be more cost effective than expendable systems. Unfortunately, the pre-Challenger shuttle operation lagged far behind expectations. This prompted the then Under Secretary of the Air Force, Pete Aldridge, to ask Congress to approve the purchase of several Titan unmanned expendable launch vehicles to meet the Air Force requirements. This proved to be a wise decision when the shuttle disaster occurred in early 1986. This accident coupled with the failure of two Titan launches brought the Air Force launch activities to a grinding halt.

The Air Force soon regretted another decision that committed all large satellites to the shuttle due to design requirements to optimize the shuttle cargo bay. The Titan problems were soon fixed and coupled with more orders for over thirty additional

expendable launch vehicles, the Air Force began to launch its needed payloads into orbit once again. Secretary Aldridge has since decided that the Air Force will now launch most of its future payloads on its own vehicles, due to the high cost of the shuttle and its reduced launch schedule (7). Unfortunately, the redesign of the shuttle to make it safer degraded its payload capability making it incapable of placing Air Force payloads of sufficient weight into polar orbits from Vandenburg AFB. This may also preclude launching of the shuttle from Vandenburg AFB. Secretary Aldridge felt the earlier decision to solely use the shuttle cost the nation dearly and will continue to cost us in the future as we scramble to catch up on our large payload backlog.

These accidents contributed to a launch backlog of satellites that may last up to at least three and a half years (12). In addition, the loss of a large shuttle availability left the Air Force with no way of placing its large shuttle designed payloads into orbit. This new requirement fueled the desire to look at new systems as a solution to the continuing problem of high launch costs. The quick solution was to purchase new versions of proven systems such as the Delta, Atlas and Titan launch vehicles. Table 1. shows typical data and costs for the current versions of these systems (12). Figure 2 shows what typical versions of these vehicles look like. However, these systems still cost over $2000 per pound to use.

The advent of the Strategic Defense Initiative program and the space station generate the need for a new heavy lift vehicles capable of placing oversize payloads of over 150,000 lbs in LEO at costs approaching $300 per lb (19). The current technologies as implemented fall far short of these goals. In order to meet these requirements, the new system will have to not only incorporate new technologies, but operate in a new infrastructure. This infrastructure will speed up the development, production and launch preparation while increasing reliability and mission effectiveness. The study

Table 1. Current USAF Expendable Launch Vehicles

	Titan IV	Delta II	Titan II
Length	204 ft 126 ft	111 ft	
Width (main rocket)	10 ft	8 ft	10 ft
Take-off wt.	1900K lb	509K lb	340K lb
Total Thrust	2200K lbf	1200K lbf	474K lbf
Payload			
low polar	39,000 lb	11,100 lb	4,200 lb
geo-synchronous	10,200 na	na	
First Flight	Fall 1988	Fall 1988	Summer 1988
On Order	23	28	14
Cost	$83M	$28M	$24M

of what technologies to use and how to effectively operate the system to reduce LCC remains an area of current research.

Space Transportation Architecture Study

The largest recent effort was the Space Transportation Architecture Study that was jointly run by Space Division at Los Angeles AFB and by the Marshal Space Flight Center (NASA) in Alabama (13). The study was the result of National Security Decision Directive 164 which initiated a study to look at manned and unmanned launch vehicles that could meet the nation's needs through the year 2000. These efforts looked at numerous system concepts, mission models, production facilities, propulsion technologies and system integration to determine possible alternatives for the future space system. A major result was the trade-off between expendable and reusable systems and what conditions favored their implementations. A major impact on the LCC was the role of reliability and how it drove overall costs and decisions. This report indicated the difficulty in assessing system trade-offs and impacts of the changing requirements. This study was the first of many that highlighted the

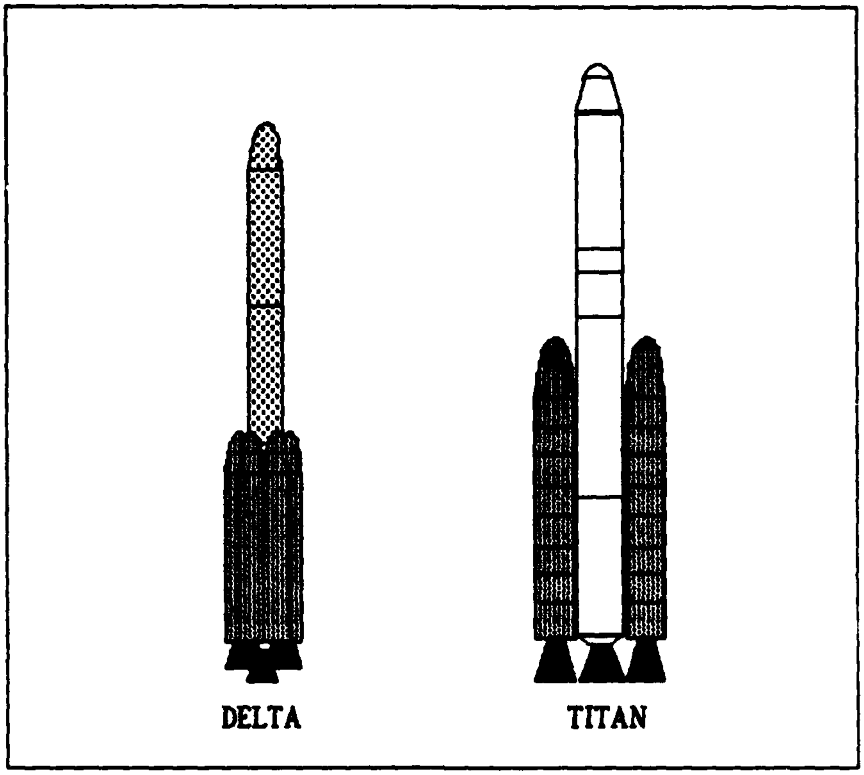

Figure 2. Delta and Titan Launch Vehicles

importance of not only improving ground and space operations, but recommended they be considered a major part of any new design.

Reliability, Cost and Infrastructure

Reliability plays a significant role in determining LCC for a proposed system. Perkins writes that the true cost of a system must include the cost of unreliability amortized over the life of the vehicle (18). The level of assumed reliability used in the LCC study should be realistic based on past similar experience. For instance, the shuttle was advertised to be .997 reliable with a useful life of 100 missions. Giving the shuttle the maximum benefit and considering the failure as occurring in 25 flights, this represented a demonstrated reliability of 96%. The cost of the failure in terms of

downtime, lost payloads, backlogged payloads, redesign work, investigations and the cost of the lost shuttle exceed five billion dollars. When this is allocated over the 25 flights, this increases the net cost by over $3000 per pound. For comparison, Table 2 lists the success rates for past launch vehicles broken down into the solid and liquid propulsion results (6). The average reliability in near 98% with a confidence level of 98% due to the large aggregate sample. Notice the shuttle has the worst statistics due to its small number of missions.

Table 2. Operational Results of Past Propulsion Systems

System	Solids	Rel	Liquid	Rel	50% LCL
Saturn	n/a	n/a	17/17	100%	96%
Atlas-Centaur	n/a	n/a	56/58	96.6%	95%
Delta	145/146	99.3%	177/180	98.3%	98%
Shuttle	24/25	96%	25/25	100%	95%
Titan	75/76	98.8%	144/147	98.0%	98%
Total	244/247	98.8%	419/427	98.1%	98%

The mission life of a vehicle is the expected value of the number of flights for a value R (reliability) and is equal to 1-1/R for a binomial distribution of events. As the number of events increase, this approaches the Poisson distribution which has a probability of 1-1/e for the expected value. From this we can see that the probability of at least one loss in n flights is:

$$P = 1 - R^n$$

Therefore, if R= 0.96 and n = 25 flights, the probability of at least one failure is 0.64. Assuming a probability of 50% for the first failure with a high vehicle reliability of

99%, one finds that this happens with only 69 flights. Dividing this 69 flight period by NASA's proposed schedule of 24 flights per year indicates a better than 50% chance of the first failure in less than three years. Figure 3 shows the number of flights for loss probabilities in the high 98 to 99.5 percent region (6). This is probably an optimistic reliability prediction and yet there is a better than fifty percent chance of at least one failure in the first fifty to one hundred flights. The bottom line to this example is that given historical reliability rates, chances are good that failures

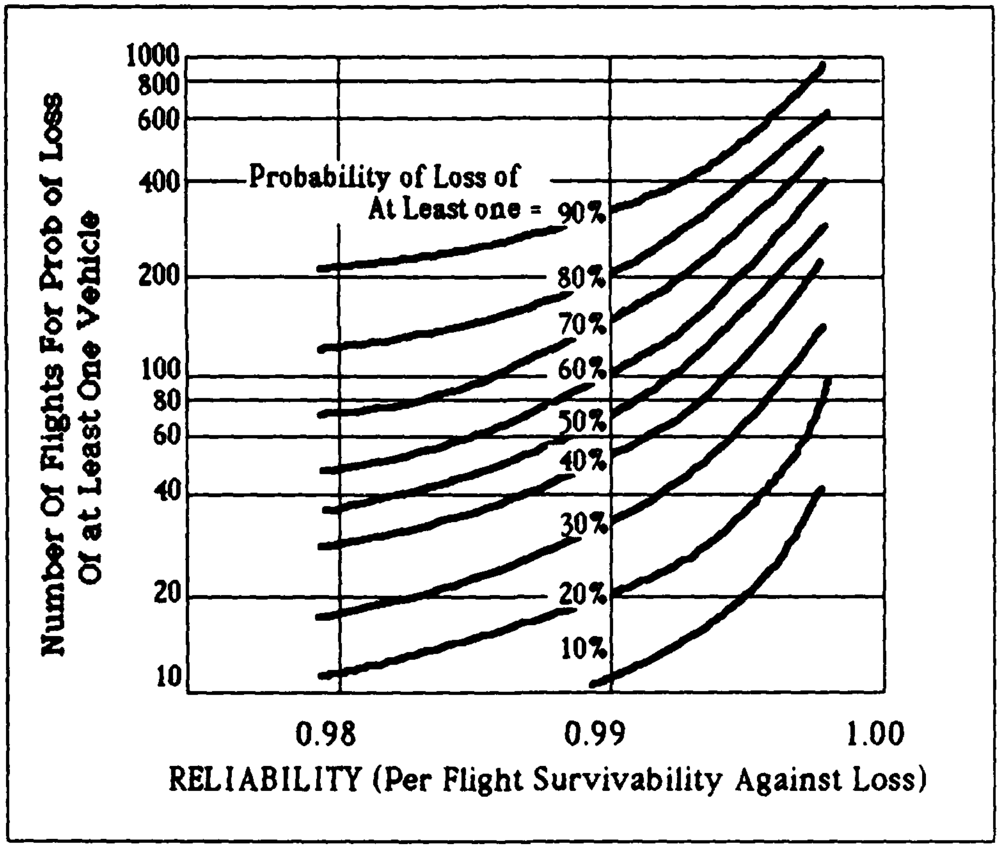

Figure 3. Expected Time to Loss of First Launch Vehicle

will happen and therefore these costs should be included when determining life cycle costs for vehicle acquisitions.

The Congressional Budget Office studied the impact of the Challenger accident (15). Prior to the accident most payloads were destined for shuttle launches due to the estimated lower costs and the decision to rely solely on the shuttle. The study concluded that post-Challenger shuttle operations will no longer have a cost advantage nor will it attain high launch rates in the near future. The report concludes that expendable launch vehicles (ELVs) will fill the void in the near-term in a cost effective manner while attaining a reasonable level of reliability. A similar report sponsored by the Office of the Under Secretary of Defense for Acquisition concluded that unmanned, expendable vehicles will fill the current void (6). The authors felt the shuttle's operational costs were still lower than ELVs, but the expected low shuttle launch rates would swing the momentum to the ELVs.

The impact of relatively low attained reliability sparked a series of studies sponsored by the Air Force Astronautics Laboratory (18). These studies focused on low cost launch systems that had near-term deployment options. Rockwell looked at expendable liquid propulsion options for a family of vehicles with a liquid core booster using either liquid hydrogen and oxygen or hydrocarbons and liquid oxygen (23). The system would be modular so it could handle different sized payloads and orbit requirements. The study indicated the need for large scale production technologies and improved system reliability. Large scale production technologies would replace the current manpower intensive production methods used on current systems. This would involve the use of assembly line technologies, robotics and computer monitored quality control techniques.

Aerojet Corporation is also looking at this area (16). They believe the solution lies in a family of modular rockets with an expendable core surrounded by a cluster of

smaller booster rockets. The study indicated a major requirement for success in lowering costs is a change in manufacturing technology. Current systems are almost hand-made and assembled, so production line technologies similar to the aircraft industry would be adopted. The study also recommended that management create a new information system that would allow quick access to system data for all required personnel.

Martin Marietta Denver Aerospace looked at developing a system using advanced technology and manufacturing techniques to produce a low cost system (1) The main component studied was a low cost cryogenic propulsion system. The designers identified high recurring cost elements of the traditional ELVs and looked for manufacturing technologies to lower unit costs. The results of the study were highly dependent on assumed reliability levels and launch rate predictions.

The major thrust of General Dynamics ELV study was to identify ELV concepts, technologies and system design approaches to minimize overall costs with a resulting order of magnitude cost reduction (5). The authors determined that the major cost drivers for ELVs were the rocket engines, propellant tanks, structure and fluid systems. Manufacturing costs were driven by production rate and lot size, design, complexity and manufacturing processes. The study concluded that modularity of engines, commonality of components and advanced manufacturing techniques were the key to reducing ELV costs.

Infrastructure refers to the total system that impacts the launch vehicle (19). This includes the research and development facilities, production and manufacturing plants, operations facilities and recovery systems as shown in Figure 4. Other major components include the data processing and information systems, the management system and the communications networks. Traditional planning for a

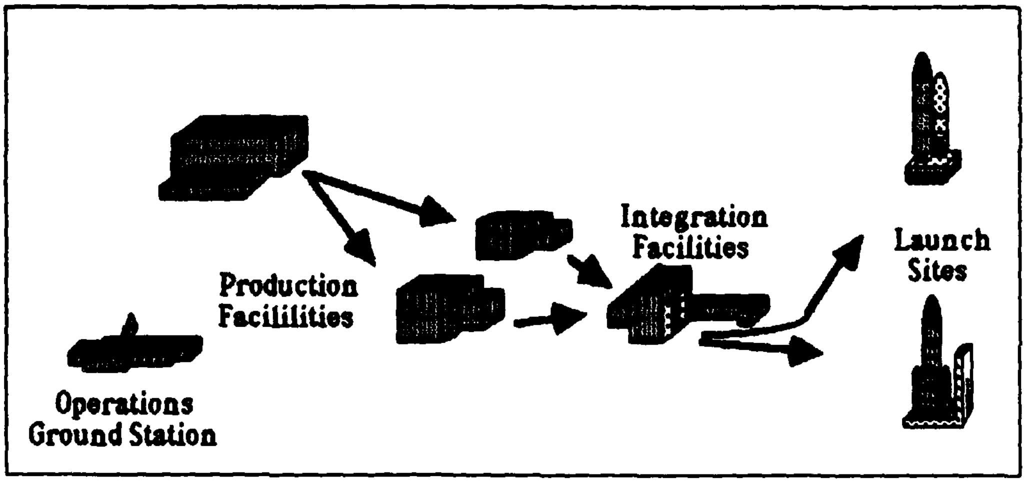

Figure 4. Typical Infrastructure Components

new vehicle placed the majority of the effort on the actual launch vehicle and related hardware. These past systems relied heavily on the existing infrastructure for support and therefore, inherited the cost of that infrastructure. The emphasis was on successful launches more than on cost effective launches. This was a practical solution since many of the programs were of short durations involving few launch vehicles.

Contrast this to the Soviet Union's method of operation (8). The Soviets use a fleet of modest, low cost satellites for their space operations. These satellites must be replaced frequently so the Soviets maintain a large fleet of launch vehicles. This allows them to use mass production techniques and to perfect the manufacture of these launchers. This also gives the Soviets the capability to develop a large inventory of launchers that can be used on short notice to replace a failing satellite or a failed launch. As an example, two failures of the Soviet SL-12 in early 1987 were met by new launches in 3-7 weeks. Contrast this to the most recent U.S. Titan failure in early 1986 which caused a downtime delay of almost a year. These long production runs have enabled the Soviets to produce a very dependable system of launchers that exhibit high

rates of reliability. In 1987, the Soviets launched 97 vehicles with only three launch failures. This compares to only 15 launches for the rest of the world. This high rate of production has allowed the Soviets to design an infrastructure that takes advantage of many production attributes proposed for ALS. The most of important of these are on-site production and integration facilities which reduce the requirements for a large support force.

A major part of the ALS cost reduction concept is the design of a new infrastructure (7). The manufacture of the components will be centralized at or near the launch site to reduce transportation and handling of the components. This alone will eliminate much of the damage and inspection burden facing current systems. If the production and assembly facilities are near the pads, then the vehicles can be delivered straight to the pad as needed. This eliminates a large part of the standing army of technicians and scientists that currently work at the plants, assembly buildings and launch sites. The same people can work with the vehicle from production through launch, instead of having to duplicate this capability at each site. The complex space system used by the Air Force requires a group of highly trained and skilled personnel that must be paid regardless of launch rates or downtime. These groups of experts are duplicated at many of the different sites within the current infrastructure. This becomes an expensive task since the current U.S. space system currently makes only random launches of very expensive satellites.

Past Modeling Efforts

Several authors looked at how to perform the needed analysis to determine the future design of the ALS. Brigantic did a study to determine whether the main engines for ALS should be expendable or reusable based on cost and reliability considerations. He used a cost estimating method called TRANSCOST (2) acquired from

Space Division at Los Angeles AFB to predict system costs. This particular model broke launch systems down into various sub-components and then used historical cost estimating relationships (CERs) to determine costs. The model looked at all phases of development from research and development through launch operations. It was composed of a collection of tabulated CERs that the analyst could use manually or place in a computer program. The CERs were incorporated into a small Basic program specifically written for the task.

The Air Force Astronautics Laboratory is working on a LCC model called the Micro Economic Leverage Investment Negotiator (MELVIN) (19). Using this model the user can design a launch system based on input requirements and specified technologies. It is more detailed than the TRANSCOST model, but has not yet completed validation. It has the capability to model a large variety of systems and to analyze many mission models and scenarios. The model can run on a personal computer (PC) or on a VAX mainframe computer. The code has been used for several design studies over the past year with emphasis placed on determining system reliability sensitivity. The code has the capability of producing highly detailed studies, but requires a large investment in time to learn to run the code and to understand its numerous engineering and costing routines. The code does some costing analysis, but is primarily used for evaluating the performance of new propulsion technologies.

Air Force Studies and Analysis (AF/SA) is looking at the concept of creating a space systems decision analysis tool called STARFLEET (11). The program will be PC compatible for use by headquarters level analysts to provide needed data to support decision makers. The specification calls for the model to perform database management, provide for a simulation mode for either deterministic or stochastic system modeling, and to provide advanced output and report generation capabilities. The model should be robust enough to handle a wide variety of scenarios, yet have

enough fidelity to provide accurate data for planning, programming and budgeting decisions. The model will assist decision makers in determining the associated costs and management requirements involved with obtaining advanced satellite systems and related launch assets.

All of these efforts stress the need to look at the total LCC. Life cycle costs refers to the total costs of a program from the beginnings of the research and development to the launch of the final mission (7). This should include all costs that are relevant to the system being studied. This includes direct costs such as production and operations which are specific to individual vehicles. There are also indirect costs such as research and development, unreliability and overhead that must be applied to the total program.

Several factors affect these costs as applied to the ALS system. First, the total number of vehicles built will affect the cost. This is due in part to economies of scale which tend to lower unit costs as more units are produced. Another factor is the production rate per period. If a production facility is only operating at partial capacity or at a surge capacity, this will normally increase unit cost. System reliability impacts the total system cost so any expected failures should be amortized over the life of the system (19).

Several major themes run through these studies. Most indicate a need to improve and demonstrate high reliability. The authors indicate that the new systems will need to handle a variety of payloads, both in terms of size and launch rate. Many of the proposed systems base costs on assumed flight rates, but their expected costs will need to be determined if the launch rates drop or increase. Several contractors are proposing new or drastically improved manufacturing facilities and launch sites. This would represent a major investment of future funds, most of which will come at the

expense of other programs. The sensitivity of the system to these assumptions will need to be analyzed.

All sources cited indicate the need for an analysis tool that will provide insight into the decisions that will be made concerning ALS. The major requirement seems to specify a user-friendly model that the analysts can easily learn and use. It should operate on a PC with relatively short run times and be adaptable to many launch vehicle system configurations and scenarios. In summary, all sources expressed a desire for a tool that will enable them to quickly perform "what if" exercises for a wide variety of questions.

System and Software Selection

The analysis groups at the ALS office and at the AFAL both used Macintosh computer systems and desired a program that would operate on these computers (21). The choice of a modeling environment centered around three options. The first was to use a traditional programming language such as Fortran, Basic or Pascal. This idea was discarded since several past cost models using these languages had proven hard to learn or understand by new personnel. MELVIN, which was developed at AFAL, is a Fortran model. Like other models, it proved to be difficult for new analysts to learn or modify for other analysis tasks. Another option was to use a simulation language such as SLAM or Simscript. A quick check of personnel at the ALS and AFAL showed that most personnel were unfamiliar with the languages or the technique. The technique does offer powerful analytical capabilities, but was deemed too complicated for the occasional user who lacked formal training in the area. The typical analysis required would be deterministic and not require the stochastic analysis. Finally, most simulation languages would not run on Macintosh computers. The final method considered was the use of spreadsheets. The ALS office were already using

spreadsheets for some analysis tasks and suggested that Microsoft Excel be used. The AFAL analysis group had not used spreadsheets, but a quick tutorial demonstrated the merits of the software.

This background indicated that a spreadsheet environment offered an excellent means of studying the problems. Most spreadsheets are relatively easy to use compared to writing or editing programs written in higher level languages. Also, the list of possible users represent people who usually can not invest large amounts of time in detailed studies. This analysis method provides these people with a quick way of determining results using minimum inputs in an understandable format. The underlying software provides well written documentation, so the user can concentrate on the system relationships and not the idiosyncrasies of a programming language.

The spreadsheet software chosen for this effort was Microsoft Excel for the Macintosh (4). The Excel software was widely available in other analysis shops so the final model would be portable. Documentation for learning Excel was readily available either with the software or from secondary sources. EXCEL is now available for MS-DOS, so the data bases should be transportable to machines using this version of the spreadsheet. Finally, Excel databases and programs could be translated into other MS-DOS spreadsheets such as Lotus 1-2-3 with minimal difficulty if a Macintosh computer was unavailable. The software requires the use of a Macintosh with at least 512K of random access memory (RAM). The computer should also have either two floppy disk drives or a single disk drive and a hard disk. All output described can be printed on the standard Imagewriter printer for the Macintosh, but a laser printer is highly recommended to improve graphics quality.

Spreadsheet Environment

The spreadsheet environment offered a great deal in meeting the problem statement requirements. As implemented on the Macintosh it is very user friendly. Most *operations* and *commands* are contained on pull down on-screen menus so no extensive training is needed. The spreadsheet itself as shown in Figure 5 is basically a large accountant type ledger where one makes entries electronically into individual boxes or cells. These entries may take the form of numbers, commands, references to other cells, analytical equations, logic conditions, names or text. The power of a speadsheet is its ability to present data in basic presentation type format while having a large complex analytical capability hidden behind the cells. This enables the analyst to enter a database and then use analytical and logical relationships to derive the needed results. An excellent guide for learning Excel is "Excel in Business" written by Douglas Cobb and published by the Microsoft Press (4).

	A	B	C	D
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Figure 5. Blank Excel Spreadsheet Cells

Excel offers a complete graphics package that allows one to create presentation graphics from any part of the database or the results. This feature is of critical importance to the analysis personnel since most of their tasking is for quick analysis

that requires a presentation quality graphic showing the results (19). The software provides six types of of graphs: column charts, area charts, bar charts, line graphs, pie charts and scatter diagrams. These graphs may be combined or overlayed with each other to create a wide assortment of data presentation formats. In addition, all or part of the database may be printed out as tables to present data as needed. An extensive tutorial on this aspect of EXCEL is also provided in Cobb's book (4).

III. STARFLEET Cost Model

This chapter presents the STARFLEET life cycle cost model and the costing relationships used in it. The first section will briefly describe the structure of the spreadsheet model as it would appear to the user on the screen. The next section presents an overview of the model describing how it works and how the various sections interact. The remaining sections will describe the individual parts of the model in detail.

STARFLEET LCC Spreadsheet Layout

A spreadsheet format is used to provide a structure for the various components. The layout of the major modules used in the model and their locations on the spreadsheet are shown in Figure 6. The input module, located in the upper left quadrant, contains many of the key parameters used in the calculations. Inputs that are frequently changed when modeling systems or doing sensitivity analysis are located in this module. The output module, located in the lower left quadrant, is where

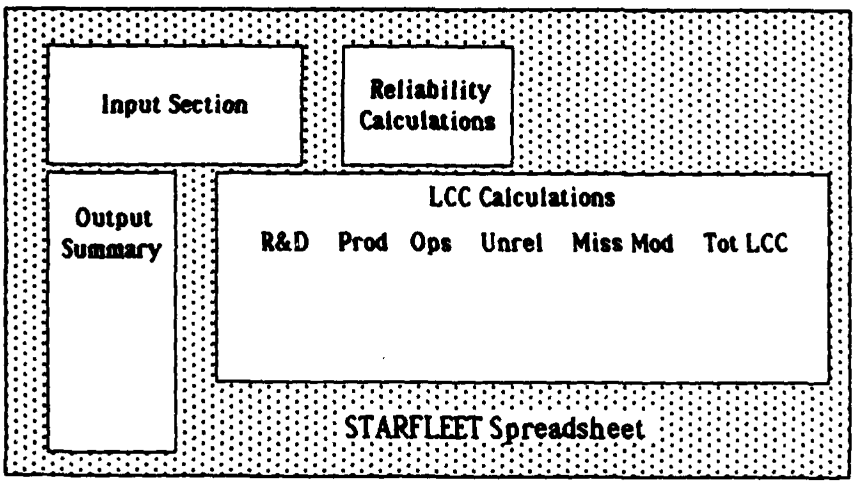

Figure 6. STARFLEET Spreadsheet

a summary of key cost and operational data is located. This data represents key output parameters frequently needed by the user. By placing the input and output modules close to each other, the user can change the inputs and see the results quickly without having to search the entire spreadsheet. The reliability module is located in the upper middle part of the spreadsheet. Most of this module contains input data so it is placed next to the input module. The results from this module transfer to the main LCC calculation module.

The remainder of the spreadsheet contains the cost model. This is broken down into four key cost areas: research and development (R&D), production, operations and unreliability. A major driver of these costs is the mission model which is defined as the number of flights per years for the life of the system. Finally, in the far right hand side of the model are the total cost calculations which are based on these five key inputs. Each of these sections will be covered in detail and actual modules as they appear on the screen will be shown. Appendix A contains a full printout of the spreadsheet for detailed study. Appendix B contains the modified model that performs stochastic analysis. Appendix C contains a listing of the infrastructure model. Appendix D contains a listing of all key equations used in the spreadsheet models.

The model uses yearly costs throughout the initial modules. These costs are then discounted based on an input discount rate after all yearly costs have been summed. All costs not labeled as discounted costs are in actual yearly costs.

The model shown in this chapter models a generic ALS system. This model can be modified to model other systems or to more accurately model a particular system. This process involves obtaining the required data for the particular system from the contractor or experts on the system's characteristics. The spreadsheet is changed by editing the current cost equations to more accurately reflect the cost estimating

relationships for the new system. Editing the spreadsheet involves making changes in the individual formulas for minor changes. Major changes would involve inserting new cost formulas for new components or else increasing the level of detail for existing components. For example, current operation costs are calculated using a single cost formula for each launch site. This single cost formula could be expanded to describe the facilities, personnel, equipment, raw material and management overhead at each site. Formulas for each would have to be developed and proper input data inserted into the model. The user would have to be careful to make the necessary changes to all parts of the model that were affected. A new cost relationship might simply add to an existing summation of like-costs or it might impact cost in several parts of the spreadsheet.

LCC Model Structure

The LCC model contains eight major modules as shown in Figure 7. The input module contains most of the frequently changed input parameters used in the cost estimating relationships. This data is then transferred to the production, operations and unreliability calculation modules. The research and development (R&D) input parameters are directly input into the R&D module rather than in the input module. The unreliability calculation module calculates the costs of failures and inputs this data directly into the unreliability costs module. The production, operations and unreliability modules compute their respective costs based on the input mission model (number of flights per year). These three costs are then summed with the R&D costs to calculate the LCC for the input system.

Input Module

The first area the user encounters is the input module. This is a ledger type area where the input parameters can be quickly changed. Figure 8 shows what part of the actual input screen would look like. This part of the input allows the user to

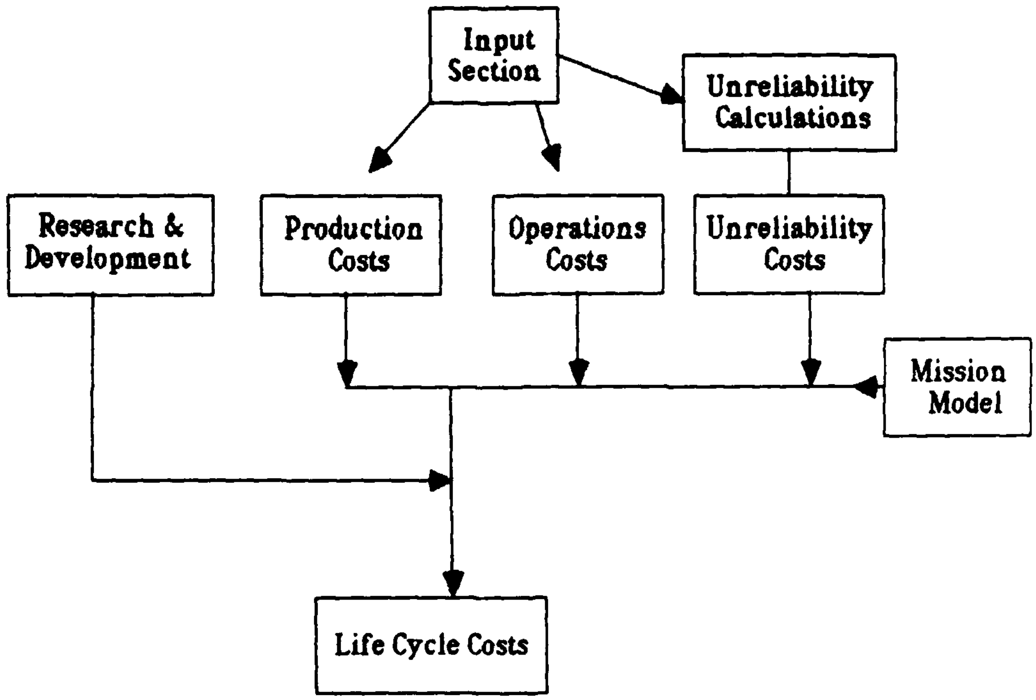

Figure 7. Life Cycle Cost Flow Model

change the learning and production curve factors as well as the management learning curve factor (these will be explained in the main model section). In this example, the proposed ALS vehicle is composed of a first and second stage propulsion system. The payload and other miscellaneous hardware is located in a generic structure called the shroud. For instance, the user can input either the learning rate (95%) or the actual factor. The learning curve factor is computed from the input learning curve rate.

	A	B	C	D	E	F
1		INPUT PARAMETERS			RATE	FACTOR
2		STG1 LEARNING CURVE RATE			0.950	-0.07400
3		STG1 PROD CURVE RATE			0.947	-0.07856
4		STG2 LEARNING CURVE RATE			0.890	-0.16812
5		STG2 PROD CURVE RATE			0.958	-0.06190
6		SHROUD LEARNING CURVE RATE			0.900	-0.15200
7		SHROUD PROD CURVE RATE			0.940	-0.08927
8		PROD PROJ MGMT LC RATE			0.930	-0.10470

Figure 8. Cost Model Input Screen

Figure 9 shows the rest of the production learning curve input data. This covers the data for the operations, management and spares usage rates. Initial costs for the vehicle components are also input at this point. As a more detailed model is built, this input section can be expanded by inserting data and parameter definitions into the spreadsheet. Note that in normal operation, the spreadsheet screen output shows only the results of the calculation. The formulas can be seen by highlighting the individual cell with the mouse to show the underlying formulas.

	H	I	J	K	L
1				RATE	FACTOR
2	ETR OPS LC RATE			0.900	-0.152
3	WTR OPS LC RATE			0.900	-0.152
4	SPARES USAGE LC RATE			0.910	-0.136
5	OPS PROJ MGMT LC RATE			0.930	-0.105
6					
7	STAGE 1 INITIAL COST			47.8	
8	STAGE 2 INITIAL COST			102.7	
9	SHROUD INITIAL COST			21.6	

Figure 9. Production Input Data

Unreliability Calculations

The reliability input calculations are shown in Figure 10. This is a combination input and analysis module. The output from this module details the cost of unreliability for launch systems based on user input data. The analyst inputs the expected *reliability rate* (N2-P3) and a variety of penalty and cost data. The first, a downtime penalty, refers to the cost per month of the delay following an accident. The maximum recovery time is how long the system is delayed until the next launch. The surge fraction tells how much above normal launch rates the system can operate at in order to reduce any backlog of payloads following a delay or disaster. The additional cost of surging is assumed to be in the downtime penalty. The backlog fraction indicates how many of the original payloads can wait to be launched until operations resume. The cost per pound input is used to estimate the cost of the lost payloads and the downtime cost estimates the cost of the delays. As a simplification, this assumes the cost of all lost payloads and delays caused by failures are the same.

	N	O	P	Q	R	S	T
1	COST OF UNRELIABILITY						
2	REL RATE		0.99		# OF YEARS		15
3	DOWNTIME PENALTY		3.00		ETR FLIGHTS		133
4	MAX RECOVERY TIME		6.00		ETR PAYLOAD		144,000
5	SURGE FRACTION		0.35		ETR LOADFACTOR		1
6	BACK LOG FRACTION		0.95		WTR FLIGHTS		203
7	PYLD COST/LB		$10,000		WTR PAYLOAD		107,900
8	DOWNTIME COST		$50,000,000		WTR LOADFACTOR		1

Figure 10. Reliability Input Module

Columns R-T in Figure 10 represent the mission model used to determine the costs of the failures. This shows how many years the model runs, the number of launches and what type of launches in terms of launch sites. It also shows the payload per flight and the average load factor. This data can be calculated in the regular

mission model section and transferred into this section or manually input. The data for this cost module would be obtained from historical data bases or from estimates.

	V	W	X	Y	AA
2	ETR NET LOAD	144,000		DOWNTIME ($M)	$504,000,000
3	WTR NET LOAD	107,900		PL LOSSES	$4,105,570,000
4	# OF FAILURES	3.36		TOT LOSSES	$5,759,129,600
5	YRS SYS DOWN	0.84		TOTAL/FLT	$17,140,267
6	# FLTS MISSED	19			
7	FTLS UNFLOWN	1			
8	TOT PYLD UNFLN	114,956			
9	LOST VALUE	$1,149,559,600			

Figure 11. Reliability Costs

The previous inputs (Figure 10) are used in the remainder of the unreliability section (Figure 11) to determine the expected unreliability costs over the life of the system. Net load data is an abbreviation for net payload and refers to the assumed payload for flights operating out of either the eastern or western test range areas. The remainder of the terms are calculated as follows:

Number of Failures = (1- Rel Rate) X Total Number of Launches

Years System Down = Number of Failures X Downtime Penalty

Number of Flts Missed = Years System Down X Flt Rate

Number of Flts Unflown = Number of Flts Missed X (1-Backlog Fraction)

Tot Payload Unflown = Flts Unflown X Average Payload per Flight

Lost Value of Unflown Pyld = Tot Pyld Unflown X Payload Cost per Pound

Downtime Cost = Years System Down X Downtime Cost per Year

Payload Losses = Cost of Payload per Pound X Number of Failures X Ave Pyld

Total Losses = Payload Losses + Downtime + Value of Unflown Payloads

This deterministic method of modeling failures provides a good first look at the costs of reliability and the impact on the program. It makes the assumption that the failures are spread evenly over the program and that all failures have the same impact. This is rather simplistic, but is only meant to be used as a first-cut method to gain insight into a new system. A further improvement might be to model the cost of the loss using a learning curve relationship. This would decrease the cost of a failure occurring later in the program. Learning curves will be discussed in detail in the production costs section of this chapter. A *modification of the main program* will be discussed later to show how to compute this cost by doing multiple stochastic simulation runs for the launch system. A brief discussion is included to detail the difference in the cost of a failure based on when the losses occur.

The remaining modules make up the majority of the LCC model. These modules use the inputs from the previous modules to compute the individual component costs that make up the LCC. The four major cost categories are the initial research and development investment, production, operations and unreliability costs. These modules are a mixture of input data and cost calculations.

Research and Development Investment Costs

The development costs for the vehicles, the production facilities and the operational facilities are contained in the first module. A breakdown of these are shown in Figure 12 as the data would actually appear on the computer screen. The first cost (column B) is technology which would represent the investments in original research at government laboratories and with contractors. The vehicle cost (column C) represents advanced development preceding production. The facilities investment (column D) would fund new production technology and items relating to new system infrastructures. The non-recurring production (column E) represents investments in

	A	B	C	D	E	F	G
11			ALL AMOUNTS IN MILLIONS ($)				
12		TECHNOLOG	VEHICLE	FACILITIES	NR PROD	TOTAL INVESTMENT	
13	1989	175.0	5.8			180.8	
14	1990	154.9	46.2	122.0		323.1	
15	1991	209.9	76.9	290.0		576.8	
16	1992	173.3	365.6	315.0		853.9	
17	1993	126.6	923.2	424.0		1473.8	
18	1994		1058.4	1242.0		2300.4	
19	1995		1244.0	977.0	287.7	2508.7	
20	1996		1095.20	776.0	287.7	2158.9	
21	1997		666.5	682.0	287.7	1636.2	
22	1998			414.0		414.0	
23	1999			58.0		58.0	
24	2000					0.0	
25	2001					0.0	
26	2002					0.0	
27	2003					0.0	
28	2004					0.0	
29	2005					0.0	
30	2006					0.0	
31	2007					0.0	
32	2008					0.0	
33	2009					0.0	
34	2010					0.0	
35	2011					0.0	
36	TOTAL	839.7	5481.8	5300.0	863.1	12484.6	

Figure 12. Initial R&D Investment Inputs

new production facilities. These costs normally occur during the first few years of a program's development. Research and development for the vehicle and the facilities is almost complete at this point. Once production starts, it is difficult and expensive to make major changes to either the vehicle or the facilities. These changes, if warranted, are usually implemented during a future phase of production or new vehicle system.

The user provides the data for the Research and Development module. This is done in the same fashion as the input module and unreliability calculation module.

The needed information would be provided by the system contractor, historical data or estimates from cost analysis groups. This input format allows the user to input the desired investment in terms of amounts and timing of expenditures. The model can be changed to add other cost elements by inserting a new column for the category and inputting the new data.

Production

Costing of the production system is contained in the module shown in Figure 13. These calculations combine production and learning curve equations to determine yearly costs. The analyst provides the learning and production curve factors, first unit costs and a yearly flight rate. The cost factors and first unit costs are inputs that are transferred from the input module described earlier. Figure 13 shows the production module from the cost model as it appears on the computer screen. The rows refer to the years of expected operation beginning with 1989 for row 13.

The vehicle is divided into three major components. These components, first stage, second stage and shroud represent the basic structure of a majority of proposed ALS systems (18). As defined in this study, the shroud is a generic term for the payload module or any other non-propulsion stage. The last category (column K) is used to predict project management costs. This management category defines inputs that illustrate the impact of proposed changes in the production method and organization.

The formulas used to compute these numbers were based on production and learning curve theory. Samples of the actual inputs for the worksheet in EXCEL format are as follows:

Excel Formulas

Stage 1

```
=K7*((AE21*AE21^F2*AE21^F3))  (first year)
=K7*((AE22*AE22^F2*AE22^F3)-(AE21*AE21^F2*AE21^F3))
```

	H	I	J	K	L
11	RECURRING PRODUCTION				
12	STAGE 1	STAGE 2	SHROUD	PRJ MGT	TOTAL
13					
14					
15					
16					
17					
18					
19					
20	154.8	298.6	61.8	0.5	515.7
21	346.3	569.7	115.2	1.4	1032.6
22	495.1	753.0	150.5	2.2	1400.8
23	452.4	657.0	130.4	2.2	1242.0
24	448.7	633.1	125.2	2.3	1209.3
25	450.3	621.6	122.5	2.4	1196.8
26	454.6	616.6	121.2	2.5	1194.9
27	460.6	615.4	120.7	2.6	1199.3
28	467.6	616.7	120.7	2.7	1207.7
29	457.3	596.2	116.5	2.7	1172.7
30	466.2	601.7	117.4	2.8	1188.2
31	475.4	607.9	118.5	2.9	1204.7
32	484.8	614.6	119.6	3.0	1222.0
33	494.3	621.7	120.9	3.1	1239.9
34	503.8	629.0	122.2	3.2	1258.2
35					
36	6612.1	9052.9	1783.5	36.2	17484.6

Figure 13. Production Costing Section

In EXCEL, the cells are referred to by column and row identifiers. The rows are labeled with numbers and columns with letters. In these equations K7 referred to the first unit cost, AE21 was the cumulative units, F2 was the learning curve factor and F3 was the production curve factor. The complete EXCEL equations for the rest of this section in addition to the entire spreadsheet are located in Appendices A and D. The equation written in standard mathematical form is shown on the next page. It combines the learning curve and production theory into one cost estimating relationship.

$$\text{Yearly Cost} = C_1 * [\, N * N^{lc} N^{pc} - (N-1) * (N-1)^{lc} * (N-1)^{pc} \,]$$

where C_1 is the first unit cost

N is the cumulative units for Year N

lc is the learning curve factor

pc is the production curve factor

This equation reduces the initial cost per unit, since the negative exponent on N makes N^{lc} and N^{pc} decrease as N grows larger. The equations for stage 2, the shroud and management costs use the same basic equations only with different first unit costs and learning and production factors. The first unit costs and factors are contained in the input module.

Learning curve equations have been used in the aerospace industry for over forty years to predict costs. The basic relationship behind learning curves is that each time the quantity produced doubles, the cost reduces by a constant percentage over the previous cost. There is some real limit to the decrease in costs, but the production quantities used in this model are relatively small, so this is not a problem. The cost reductions stem from improvements in production techniques, management efficiency and general familiarity with the production process. The relationship between the cost and quantity is a power function of the form:

$$Y = AX^b$$

where A is the cost of the first unit, X is the cumulative production quantity and b represents the slope factor of the learning curve. The term slope refers to the "slope factor" and not to the normal geometric slope definition. The slope factor (S) represents a relationship of the constant percentage to which cost decreases as the quantity doubles. The slope factor may be computed by dividing the formulas for the

respective quantity costs and then solving for the slope factor in terms of the other known quantities. This takes the form of:

$$S = \frac{Y_{2x}}{Y_x} = \frac{a(2x)^b}{ax^b} = 2^b \quad \text{or} \quad b = \frac{\log S}{\log 2}$$

S represents the decrease in decimal form (ie, 75% is .75) and the subscript x is the initial quantity before doubling (subscript 2x). Production curve theory stems from relatively new research into production efficiency (9). It assumes that costs drop as production rates increase up to some realistic process capacity. The cost model used for this is identical to learning curve models. The two relationships, learning curve and production curve theory, can be combined into one equation:

$$\text{Cost} = \text{First Unit Cost} * N^{lcf} * N^{pcf}$$

N represents the number of units produced while lcf and pcf are the respective learning and production curve factors.

This part of the model allows the user to alter the inputs to look at production sensitivities. These would include analyzing the impact of varying production and learning curve factors. These factors would change based on the type of production facility used and the investment made in improving the production technology. The actual analysis would involve inserting the cost of the new production process into the investment section and then varying the production rate factor to determine what improvements would be needed to justify the cost. If the savings were greater than the cost, then this might be a feasible technology investment. Obviously, the proposed cost savings due to the improved production factor would be linked to the production investment. Another major change would be in the first unit cost estimate since this input impacts the entire cost for that component during the life of the production run The analyst could also alter the production schedule by varying the yearly rates at

which the vehicles are made. This would reflect changes due to production capability, project funding and launch requirements for vehicles.

Operations

The actual launch operations cost of the space fleet are modeled as shown in Figures 14 and 15. The rows refer to the year of the model starting with 1989 in row 13. This module includes launch costs for two separate launch facilities, propellants for the vehicles, spare part usage, training requirements for operational personnel, facility maintenance and management. These are only a few of the many items that can be modeled.

This modeling of the operational costs uses a combination of modeling relationships. The actual input screen for this module is shown in Figure 14. The rows in the figure refer to the year starting with 1989 in row *13. The facility maintenance (column N) is an input constant that was estimated to be spread evenly over the life of the system. The operation costs (columns O and P) use a learning curve model. This embodies the assumption that launch costs per flight will decrease as operations increase. This is a major assumption for ALS and is key to ALS reaching its launch cost goals. The operations were split between a west coast launch facility (WTR-western test range) and an east coast launch facility (ETR-eastern test range). These use a variation of the basic learning curve equation:

$$\text{Ops Cost} = \text{Fixed Cost} + C_1 * N * N^{LC}$$

where C_1 was the first unit launch cost

N was total launches in a given year

LC was the learning curve factor

	N	O	P	Q
11	OPERATIONS			
12	FAC MAINT	ETR OPS	WTR OPS	TOT PROP
13				
14				
15				
16				
17				
18				
19				
20				
21	69	7.2	5.9	4.8
22	69	9.7	7.2	14.4
23	69	11.6	8.7	24
24	69	11.6	8.7	24
25	69	12.0	8.7	25.2
26	69	12.0	9.0	26.4
27	69	12.4	9.0	27.6
28	69	12.4	9.4	28.8
29	69	12.9	9.4	30
30	69	12.9	9.4	30
31	69	13.3	9.4	31.2
32	69	13.3	9.7	32.4
33	69	13.7	9.7	33.6
34	69	13.7	10.1	34.8
35	69	14.1	10.1	36
36	1035	182.7	134.3	403.2

Figure 14. Operations Cost Section

The fixed cost was necessary since the operational crews and facilities generate large expenses whether launches occur or not. In this use of the learning curve, N^{lc} generated the average cost per flight so this must be multiplied by the total number of flights to get a total cost for that year. Notice that the learning curve effect starts from zero each year. This models the effect that operational changes constantly happen and that previously accrued cost efficiencies are often lost. For this model, the learning process ends after each year as a simplification. In reality, a more realistic stopping point would be based on a break in operations of a long duration compared to

the normal time between flights. Both the west and east coast operations are computed using these CERs only with slightly different factors, first unit costs and constants. To compute the total propellant used (column Q), multiply the flight rate by the input propellant cost per flight factor. The figures shown at the bottom of Figure 14 are the totals for the individual columns.

	R	S	T	U	V
12	GSE SPARES	TRAINING	PROJ MGMT	ANNUAL OPS	
13					
14					
15					
16					
17					
18					
19					
20					
21	3.3	0.8	0.2	91.2	
22	8.6	2.4	0.5	111.7	
23	13.3	4	0.7	131.3	
24	13.3	4	0.7	131.3	
25	13.9	4.2	0.8	133.7	
26	14.4	4.4	0.8	136.1	
27	15.0	4.6	0.8	138.5	
28	15.6	4.8	0.9	140.8	
29	16.1	5	0.9	143.3	
30	16.1	5	0.9	143.3	
31	16.7	5.2	0.9	145.7	
32	17.2	5.4	1.0	148.0	
33	17.8	5.6	1.0	150.4	
34	18.3	5.8	1.0	152.7	
35	18.9	6	1.1	155.1	
36	218.6	67.2	12.1	2053.1	

Figure 15. Operations Costs

The remaining operational costs are shown in Figure 15. The cost estimating relationship for spares (column R) uses a learning curve relationship similar to the flight operations costs. It uses the input first cost and yearly flight rate starting from zero each year. A linear cost relationship based on the number of flights computes

the training costs (column S). Project management (column T) costs are calculated from learning curves. As before, it assumes learning starts fresh with each new period. The annual operational costs are the sum of all costs in this section. The figures shown at the bottom of Figure 15 are the totals for the individual columns.

This operations module enables the user to analyze the benefits of improvements in operations either through new facilities, new launch methods or new management techniques. The analyst would estimate the cost of the improvement and then insert it into the appropriate investment input cell. Then, the user modifies the production equation parameter to reflect the expected cost reduction. Each part of the operations cost section can be expanded to include detailed cost relationships if the needed input data is available. For instance, the WTR operations could be broken down into components such as personnel, management, raw materials, contractor support and facility preparation and repair.

Using this initial data, a partial LCC can be computed. This is defined as the sum of the operational, production and investment costs. This data is often needed for comparison purposes since several contractors use this type of accounting method. These figures would represent only part of the total costs since unreliability and overhead charges for non-direct cost have yet to be included. A discounted version of these costs is shown later in this chapter.

Unreliability Cost

The unreliability costs are input following the operation costs. These costs are are based on data obtained from the previous unreliability calculation module. This part of the model computes the reliability cost by taking the previously calculated total cost based on an expected number of failures and distributes this cost over the individual flights. The method for computing these costs are shown on the next page.

$$\text{Unreliability Cost} = \frac{\text{Total Unreliability Costs}}{\text{Total Flights}} * \text{Flights per Period}$$

$$\text{Total Unreliability Cost} = \text{Pylds not Flown} + \text{Downtime Costs} + \text{Pyld Losses} + \text{Cost / Flt} * \text{Expected Number of Losses}$$

This provides a cost per year based on the the yearly flight rate. This calculation can be zeroed out if the analyst does not want unreliability costs included in the total cost estimate. However, by including these costs, the analyst can make valid comparison between systems that may have differing reliability levels. For instance, a low cost system with low reliability will appear to have an advantage over a more costly system that exhibits superior reliability unless one includes the total unreliability costs for both. These costs are inserted into the model as shown in Table 4. They represent a single column entry shown in the full spreadsheet printout in Appendix A (AE12-AE38).

Mission Model

The previous operations and production costs are based on the mission model. For this study, mission model is defined as the number of flights per period over a specified system life. This study assumes that payloads on these flights are fixed at 144,000 lbs for launches from Cape Canaveral and 107,900 lbs for launches from Vandenburg AFB. The mission model is an important parameter in terms of estimating the total LCC for a system. From a basic viewpoint, the total LCC is composed of variable and fixed costs. The mission model drives the variable cost, while the initial investments and overhead determine the fixed cost. The average cost per flight or cost per pound is the then the total cost of these two elements (fixed and variable) divided by the actual achieved flight rates or payloads delivered to orbit. Therefore if the

flight rate is low, the cost per mission will increase while at high flight rates this cost decreases.

The mission model contains key information about the system. It represents the analyst's best estimate as to the expected flight schedule of the system. It is assumed that the full payload capability is used on each flight. Most mission models assume a steady uninterrupted schedule that uniformly increases up to a predetermined maximum flight rate. This best case scenario is then applied to the analysis of all similar systems.

The flights shown in Table 3 represent a generic mission model for ALS. Due to space considerations, the data is presented in tabular form rather than actual screen output used previously. They are listed by year and divided into the eastern test range (ETR) at Cape Canaveral and the western test range (WTR) at Vandenburg AFB. The total flights column is just the cumulative number of flights and the flight rate represents

Table 3. Mission Model

	ETR Flights	WTR Flights	Total Flight	FLT RATE
1996	3	1	4	4
1997	8	4	16	12
1998	12	8	36	20
1999	12	8	56	20
2000	13	8	77	21
2001	13	9	99	22
2002	14	9	122	23
2003	14	10	146	24
2004	15	10	171	25
2005	15	10	196	25
2006	16	10	222	26
2007	16	11	249	27
2008	17	11	277	28
2009	17	12	306	29
2010	18	12	336	30
Totals	203	133	336	336

the flights in any given period. The mission model can be input as a random event with the flights per period derived from an input distribution based on a random number draw. This enables the user to simulate failures and delays that might occur over the life of the system. This will be discussed later as a model modification.

Life Cycle Costs

This module combines the data generated in the R&D, production, operations and unreliability cost modules and then computes the final LCC results based on a variety of definitions. Table 4 shows the final costs with the addition of overhead charges. The overhead factors range from 20-30% of the base cost. The ALS office provided this data which is based on historical data and program estimates. As defined, this individual cost data represents a general estimate of the yearly funding requirements for the program components. The partial LCC per flight represents the given year's operation and production costs divided by that year's flight rate. This figure does include the 20% overhead to arrive at the final cost per flight, but ignores the initial investment costs or unreliability costs. Only the direct variable costs associated with the launch system are included in this calculation. The partial LCC per pound data results from dividing this figure by the average payload weight for that year. A summary of these and other measures of merit are:

Partial LCC = (Operations + Production costs) per yr

Total LCC = (R&D Investment + Production + Operations + Unrel) per yr

Cum TLCC = Cumulative Total LCC used as base figure

Table 4. Overhead Costs

	TOT INV	PROD	OPS	UNREL	COST/FLT PART LCC	$/lb PART LCC
1988	235.0	0	0	0	0	0
1989	420.0	0	0	0	0	0
1990	749.8	0	0	0	0	0
1991	1110.1	0	0	0	0	0
1992	1915.9	0	0	0	0	0
1993	2990.5	0	0	0	0	0
1994	3261.3	0	0	0	0	0
1995	2806.6	619	0	0	0	0
1996	2127.1	1239	0	0	182.1	1349.0
1997	538.2	1681	109	71	114.4	867.1
1998	75.4	1490	134	213	91.9	709.5
1999	0.0	1451	158	354	82.4	636.0
2000	0.0	1436	158	354	76.7	589.2
2001	0.0	1433	160	372	72.7	562.6
2002	0.0	1439	163	390	69.6	535.7
2003	0.0	1449	166	408	67.0	519.6
2004	0.0	1407	169	425	64.8	500.5
2005	0.0	1425	172	443	63.2	487.5
2006	0.0	1445	172	443	61.6	473.1
2007	0.0	1466	175	461	60.1	465.0
2008	0.0	1487	178	478	58.8	453.1
2009	0.0	1509	180	496	57.6	446.5
2010	0.0	0.0	183	514	56.5	436.3
Total	16,230.0	37,211.6	39,675.3	45,629.8	69.8	537.9

The calculations shown in Table 5 include all costs (R&D, prod, ops, unreliability and overhead) used in determining the final cost per flight and cost per pound. The rows represent years starting with 1989. The first series (columns 1-3) uses all costs for a given year then divides this by the flights and total payloads in that year. Columns 4-6 use total cumulative costs as the basis for the yearly analysis. The cumulative total LCC accumulates all costs up to that period and divides this by the total cumulative launches. These different methods provide needed data to compare to contractor and other outside data since many of the proposed systems present cost data

in different formats using different cost bases. The STARFLEET format enables the user to define the cost basis using all or part of the cost components.

Table 5. Total LCC Result Module

Tot LCC/YR $M	Tot LCC Cost/Flt $M	Tot LCC Cost/lb $	Cum Tot LCC $M	Tot Ave LCC Cost/Flt $M	Tot Ave LCC Cost/lb $
$235.04	$0.00	$0.00	$235.04	$0.00	$0.00
$515.43	$0.00	$0.00	$750.47	$0.00	$0.00
$845.24	$0.00	$0.00	$1,595.71	$0.00	$0.00
$1,205.47	$0.00	$0.00	$2,801.18	$0.00	$0.00
$1,883.35	$0.00	$0.00	$4,684.53	$0.00	$0.00
$3,018.82	$0.00	$0.00	$7,703.35	$0.00	$0.00
$3,929.14	$0.00	$0.00	$11,632.49	$0.00	$0.00
$4,074.38	$0.00	$0.00	$15,706.87	$0.00	$0.00
$3,855.74	$963.94	$6,694.00	$19,562.61	$4,890.65	$33,962.87
$2,154.32	$179.53	$1,246.71	$21,716.93	$1,357.31	$9,425.75
$1,680.21	$84.01	$583.41	$23,397.14	$649.92	$4,513.34
$1,592.33	$79.62	$552.89	$24,989.48	$446.24	$3,098.89
$1,594.44	$75.93	$527.26	$26,583.91	$345.25	$2,397.54
$1,603.47	$72.88	$506.15	$28,187.38	$284.72	$1,977.23
$1,606.06	$69.83	$484.92	$29,793.44	$244.21	$1,695.89
$1,578.92	$65.79	$456.86	$31,372.35	$214.88	$1,492.22
$1,600.62	$64.02	$444.62	$32,972.97	$192.82	$1,339.06
$1,620.64	$64.83	$450.18	$34,593.61	$176.50	$1,225.68
$1,644.39	$63.25	$439.21	$36,238.00	$163.23	$1,133.57
$1,668.69	$61.80	$429.19	$37,906.70	$152.24	$1,057.19
$1,387.13	$49.54	$344.03	$39,293.83	$141.85	$985.10
$182.05	$6.28	$43.59	$39,475.88	$129.01	$895.88
$184.89	$6.16	$42.80	$39,660.77	$118.04	$819.71

The final part of the costing module is shown in Table 6. The total LCC data has been adjusted based on an input discount rate to determine the net present cost. The discount rate is input in the input section (Y8-AA8). The discounted LCC represents the total cost of a system discounted into a specified year's dollars (22). For example, a cost of $100 in the future is worth less than a $100 cost today when discounted. As the discount rate chosen increases, the net present cost of a future expenditure decreases.

Therefore, a system with the majority of its costs late in the program will have a lower net present cost than one that requires most of its funding in the early years. The discount rate can be chosen by the analyst based on frequently used values or based on current direction from the Congressional Budget Office.

Table 6. Discounted LCC Data

	DISC FACT 5%	TOT DISC LCC COST $M	DSC OP COST PER FLT $M	DIS OP COST PER LB $	TOT LCC PER YR $M	TOT LCC PER FLT $M
1988	1.000	180	0.00	0.00	235.04	0.00
1989	0.952	307	0.00	0.00	490.89	0.00
1990	0.907	523	0.00	0.00	766.66	0.00
1991	0.864	737	0.00	0.00	1,041	0.00
1992	0.823	1,212	0.00	0.00	1,549	0.00
1993	0.784	1,802	0.00	0.00	2,365	0.00
1994	0.746	1,872	0.00	0.00	2,931	0.00
1995	0.711	1,900	0.00	0.00	2,895	0.00
1996	0.677	1,916	123.2	913	2,609	652
1997	0.645	1,378	73.7	558	1,388	115
1998	0.614	1,096	56.4	435	1,0310	51
1999	0.585	991	48.1	371	931	46
2000	0.557	948	42.7	328	887	42
2001	0.530	912	38.5	298	850	38
2002	0.505	881	35.1	270	811	35
2003	0.481	853	32.2	249	759	31
2004	0.458	805	29.7	229	733	29
2005	0.436	774	27.5	212	707	28
2006	0.416	752	25.5	196	683	26
2007	0.396	731	23.7	184	660	24
2008	0.377	711	22.1	170	522	18
2009	0.359	690	20.6	160	65	2.2
2010	0.342	234	19.3	149	63	2.1

The LCC model described in this chapter required some detailed information on the proposed launch systems. However, cost analysis can be done using an alternate format if cost data is available. Data on past and current launch systems is available

and cost relationships can be obtained from the data. These cost estimating relationships normally take the form of a fixed and variable cost based on the flight rate for a given period. This information can be inserted in the model by deleting the detailed cost sections (R&D investment, Production and Operations) and inserting the new cost relationships. The "cost model" for a given year would then be a cell containing this new formula and requiring input from the mission model module. For example, the Titan IV would be modeled as follows (6) :

1. Delete all costing sections up to the mission model.
2. The LCC cost would be an equation similar to:

$$\text{Cost per Pound} = \frac{\$3702}{\text{Flights during Year}} + \$1682 \qquad (\$1986)$$

This provides an estimate of the costs for other systems that could be used for comparison.

Stochastic Modeling

The STARFLEET model was also modified to provide a stochastic type analysis capability similar to current simulation programs. As an example to illustrate the modification, consider the yearly flight rate. This allows the analyst to look at the impact of random failures and delays on the proposed system's LCC. For instance, a failure early in the program may have a much higher cost than one occurring on the last mission. The early failure would possibly trigger major design and operational modifications that would be used during the remaining life of the system. A failure at the end of the system's life might only trigger minor changes since the Air Force would already be transitioning into a follow-on launch system. The actual flights

would probably not occur evenly spread over a set number of years. Instead, the flight rates would probably be uneven due to delays, failures and other unexpected occurrences. These scenarios could be manually modeled by doing individual analysis runs and then weighing the output by some probability of occurrence. This would be very slow and would introduce a high degree of user bias in the input of the random occurrences.

In order to modify the model to perform stochastic analysis, certain data is needed. First, the analyst must determine the underlying distribution for the flight rate and associated failures. This distribution will then be accessed through the use of a random draw to determine potential flights, delays and failures. The user must define the outcome or penalty that will be applied to the system based on the possible outcomes. This may range from cost penalties to flight delays or a combination of both.

The actual insertion of this data into the model occurs as a substitution for the flight rate column and as an input to the LCC columns. This would be implemented as shown in the following example:

1. Generate a random number Y on U(0,1) (EXCEL provides this function).
2. Assign Y = f(X) based on the following distribution:

   for $0 < X < .8$ launch is successful, no penalty.

   for $.8 < X < .97$ launch delayed, penalty of $10M and 30 day delay.

   for $.97 < X < 1.0$ launch failure, cost penalty of $250M and 1 yr delay.
3. Based on the above outcome, assign respective penalties.
4. Insert this new data into full model to obtain new LCC.
5. Repeat individual runs until a desired confidence interval is obtained.

Using this criteria for each individual run, a new mission model is created. The mission model would need to be modified to shift the delayed launches forward in time after a delay or failure. This is done with a logic statement that checks to see if a delay had occurred, and if so would compute the number of flights shifted into the next period. A surge capability may also be added by checking to see if a backlog exists and then increase future launch rates until the backlog is reduced or another problem occurs.

Multiple runs are used to create a sample population. A spreadsheet macro was used to accomplish this (4). A macro is a program subroutine that instructs EXCEL to perform a calculation or take an action. The macro needed in this case is called a command macro. It tells EXCEL to perform a series of commands that aggregates and organizes the data from the multiple runs. Copies of this macro and of the stochastic modification for the STARFLEET model are contained in the Appendix B.

IV. STARFLEET Infrastructure Model

The major challenge of ALS is to reduce launch costs by an order of magnitude from todays $3000-4000 per pound. A significant part of this reduction comes from the new infrastructure that is planned for ALS. In addition to reducing costs, this infrastructure must provide sufficient capability to handle the proposed flight rates throughout the system's life. It should be a balanced system that has enough capability to provide the needed production and operations capability. It should take advantage of new locations (possibly near the launch site), new production methods and new methods of component transportation to reduce the total life cycle cost. A method was needed to quickly evaluate the contractors' new proposed systems to make sure they were feasible in terms of cost and operations. The second part of the STARFLEET model addresses this issue by providing a method of analysis to look at the problems associated with a new infrastructure. The purpose of this analysis is to look at the total infrastructure and determine if it has sufficient capability to handle launch demands. A secondary issue is to identify excess capability or unbalanced production. This model looks at the flow through the system of the individual components as they progress towards the launch pad. The costs associated with developing the systems to attain these new flow rates (cost would be provided in contractor's proposal) can then be input into the previous STARFLEET LCC model. These costs would be input in the technology investment, production and operations modules. This chapter begins with a brief model overview detailing the spreadsheet layout and then a description of the model flow. This is followed by a detailed look at the input module, the network calculation module and the output module.

Model Overview

The model follows the flow of the vehicle components from the production stage to final launch. This is modeled as an output from an activity that then must be transported to the next activity. In this case, the activities are production, integration, pre-launch, launch and recovery of reusable systems. The code also models storage capacity at each site and determines overages and shortages. This pseudo network flow allows the analyst to model the different flow and capacity parameters to determine a maximum or minimum flow based on the estimated capacity at each activity. The analyst can then see any benefit or problem resulting from planned system changes due to facility locations, technology insertion, schedule surges, rate changes or storage capacity changes.

The structure of the spreadsheet infrastructure model contains an input module, network calculation module and an *output module*. *Figure* 16 shows the organization of the actual spreadsheet contained in Appendix C. As a guide, the cell locations for key areas will be listed following the descriptions of the modules. All key parameters are contained in the input module (A1-I33). These types of input are activity rates, storage capacities, initial conditions and vehicle description parameters. This initial data is stored here for reference and also transferred to the appropriate areas in the network calculation module. The output summary module (A35-I70) contains all of the key output analysis from the network calculations. The data presented in this section can be customized by the user by transferring the appropriate results to this module. The output module is purposely located next to the inputs. This allows the analyst to make changes in the inputs and note the resulting change in the output without having to scroll all over the spreadsheet.

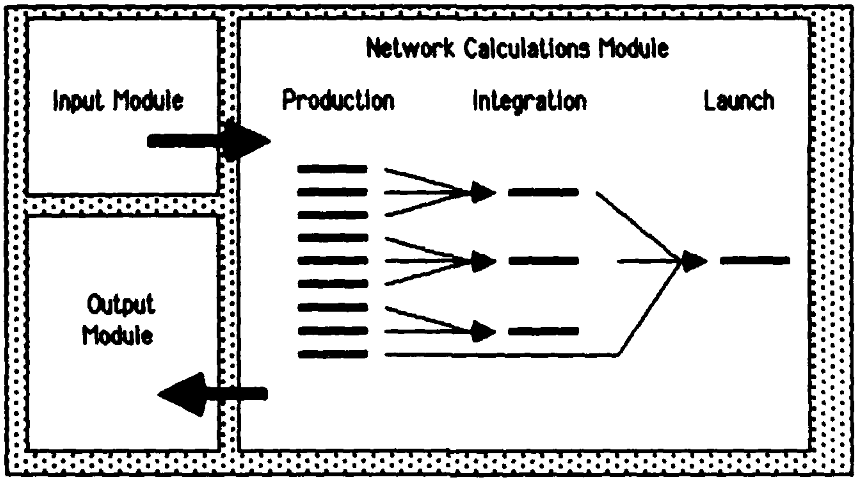

Figure 16 Infrastructure Spreadsheet Layout

All of the key analysis is performed in the network calculations module (K1-AC73). This models the flow of the individual components from the initial production facilities through integration and on to the launch site. The production of the components is modeled in the calculations on the left side of this module and the resulting components flow to the launch pad calculations on the right side. The network flow is shown in Figure 17. This models a system containing a two stage vehicle with a payload section. The first stage is called the booster stage. It is made up of one or more boosters that all contain three elements: avionics, structure and engines. Each individual booster can have one or more engines. The core stage is similar and also contains the same elements. These generic stages allow the user to model a wide variety of proposed vehicles. Integration is defined as the process of bringing together the three components to form the individual booster or core. Integration also included the joining of the fairing and platform to create the payload section. The fairing is defined in this study as the primary structure of the payload section while the platform is defined as any internal structure or support equipment needed to support the payload. All three of these major components are then

assembled to form the final launch vehicle. Hydrogen is the only system propellant modeled. It is assumed to be produced in a single facility and then transported to the launch site.

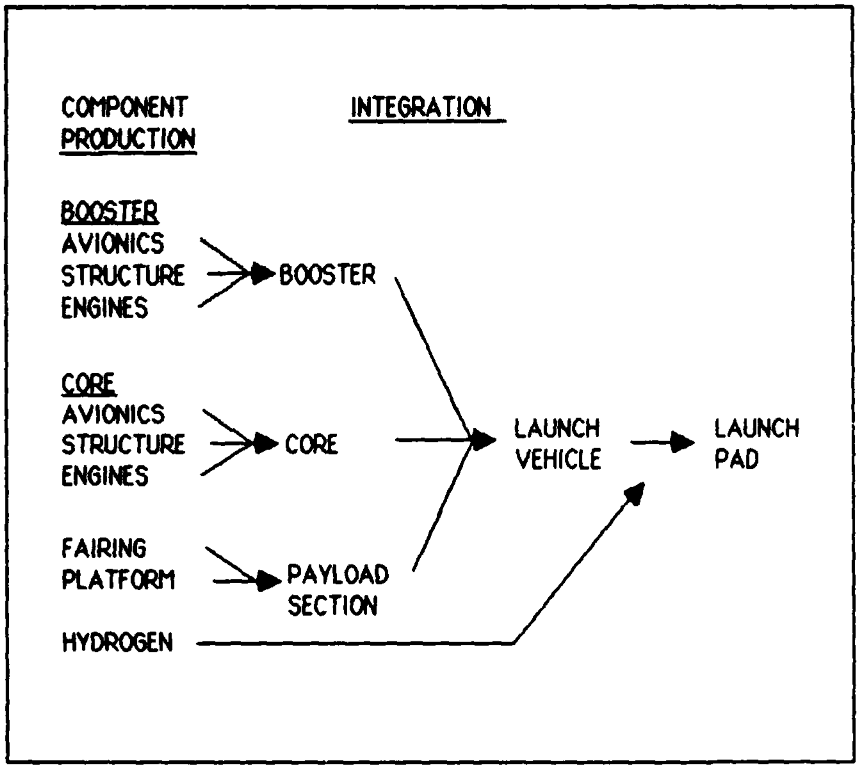

Figure 17. Network Calculation Module

Input Module

The Input module is divided into a production input area and an integration input area. The production input parameter area (A1-I11) is shown in Figure 18. The items listed in this figure are input by the user to model a system of particular interest. The input data can be obtained from historical data or from system estimates. The data shown is for a generic ALS vehicle. The number per transport batch is how many components can be transported at once in a single vehicle. The number of transport

	A	B	C	D	E
1	PRODUCTION		INPUT PARAMETERS		
2		RATE/DAY	# TRNSP BAT	TRNSP DAYS	# TRNSP VEH
3	CORE ENGINES	0.2	8	1	2
4	CORE STRUCT	0.05	1	1	1
5	CORE AVION	0.05	2	1	1
6	BSTR ENGINES	0.2	8	1	2
7	BSTR STRUCT	0.2	2	1	1
8	BSTR AVION	0.2	4	1	1
9	PYLD INTEG	0.05	2	1	1
10	FAIRINGS	0.05	1	1	1
11	HYDROGEN	45000	N/A	N/A	N/A
12					
13					
14		INIT @ PROD	INIT @ INT	STOR @ PROD	STOR @ INTEG
15	CORE ENGINES	0	0	40	40
16	CORE STRUCT	0	0	3	5
17	CORE AVION	0	0	3	5
18	BSTR ENGINES	0	0	50	50
19	BSTR STRUCT	0	0	3	5
20	BSTR AVION	0	0	3	5
21	PYLD INTEG	0	0	3	5
22	FAIRINGS	0	0	3	5
23	HYDROGEN	0	0	1,000,000	N/A

Figure 18. Production Inputs

days refers to how long it takes to deliver the component one way to the next facility. The number of transport vehicles represents how many are available for use. This initial number at production represents finished components that were not shipped out previously. The storage at production and integration is how many vehicles may be stored at any one time.

As an example, look at the input data for the core engines. The production rate at the plant was 0.2 per day. The finished products are shipped to the next facility, integration, in batches of eight using two available vehicles and taking 1 day for the trip.

The integration process inputs shown in Figure 19 look similar to production. Integration brings the separate major components together to form the final launch vehicle. This was modeled as integrating the components for the individual boosters,

	A	B	C	D	E
1	INTEGRATION				
2		PROC DAYS	# TRNSP BAT	TRNSP DAYS	# TRNSP VEH
3	CORE	25	2	16	1
4	BOOSTER	15	12	12	1
5	VEHICLE	4	1	12	2
6	PAYLOAD	5	1	6	2
7	HYDROGEN	N/A	350000	4	1
8	VEH INTEG	4			
9	PAYLD INTEG	5			
10					
11		INIT @ INTEG	INIT @ LNCH	STOR @ INTEG	
12	CORE	0	0		
13	BOOSTER	0	0		
14	VEHICLE	0	0	5	
15	PAYLOAD	0	0	1	
16	HYDROGEN	0	0	N/A	

Figure 19. Integration Inputs

core and shroud assemblies. These major components then form the final launch vehicle. The definitions of the items in this section of the input module are identical to those of the production input module.

Various process rates and vehicle parameters (A23-J33) are shown in Figure 20. The first three items, pre-launch, launch and recovery/refurbishment refer to how long these activities take to complete. The pre-launch activity would be final mating of the payload to the vehicle, transporting the vehicle to the pad and any other preparatory modifications. The launch activities are mainly final actions taken at the pad to prepare for the launch. The refurbishments and recovery activities refer to action taken to recover expendable components after the launch and to make them ready for future launches.

Row 30, column B in figure 20 shows the total number of years the model will cover and the number of operational days per year. The vehicle parameters in columns D and E describe the number of various components used on each launch vehicle.

	A	B	C	D	E
24	LAUNCH SITE			VEHICLE PARAMETERS	
25		PROC DAYS			
26	PRE-LAUNCH	6.5		ENGINES/COI	4
27	LAUNCH	2		H2 PER ENG	150,000
28	RECOV/REFURB	12			
29				BSTR/VEH	4
30	# YRS OF OPS	5		ENG/BSTR	1
31	OPS DAYS/YR	250		BSTR LIFE	20
32	#OF PROD DAYS	1250		ENG RCV/FLT	3
33				H2 PER ENG	140,000

Figure 20. Operational Inputs

Network Calculations Module

The flow of components between the production, integration and launch sites is computed in this module. Calculations are made that determine output from production facilities, number of components integrated and numbers of completed vehicles launched. The flow of components between these activities is calculated to measure against the input transportation capability. The purpose of this analysis is to look at the total infrastructure and determine if it has sufficient capability to handle launch demands. A secondary issue is to identify excess capability or unbalanced production.

Initial Production

The first set of activities is the initial production of the components. This models the individual factories where the key components are manufactured. This module models the total production output for each production facility and compares this output to the available transportation assets that will deliver the finished components to integration This module is divided into nine sections for each of the major components (K1-L73):

1. Core Engines
2. Core Structures
3. Core Avionics
4. Booster Engines
5. Booster Structures
6. Booster Avionics
7. Platforms
8. Fairings
9. Hydrogen

The first of these, shown in Figure 21, will be used to illustrate the format and calculations contained in the other eight. The first three entries repeat input data from the input section. The production rate is how many components are made per day. The initial number at integration represents finished products awaiting transportation to integration. The engine storage capacity states how many engines can be stored at the production site. Storage of these components may involve more than finding an empty place in a warehouse. This could involve a climatically controlled environment or frequent maintenance and monitoring of the components to prevent damage. Both of these types of storage could involved expensive facilities and operations. This data is placed in the module for the convenience of the user. The next item, the maximum number of engine shipments (row 7), is computed as follows:

$$\text{Max Number of Eng Ship} = \text{Integer}\left(\frac{\dfrac{\text{Tot \# of Prod Days}}{2 * \text{Trans Days}}}{\text{Number of Trans Veh}} \right)$$

	K	L	M
1	PRODUCTION		
2			
3	CORE ENG PROD		BOTTLENECK
4	ENGINE PROD RATE	0.2	0
5	INIT ENG PROD	0	
6	ENG STOR CAP	40	
7	MAX # OF ENG SHIPMENT	1250	
8	MAX # ENG STORED AT PI	8	
9	TOT ENGINES PRODUC	250	

Figure 21. Core Engine Production

This refers to the maximum capability of the transportation system that serves this production facility. This equation takes the total available production days and divides it by the number of transport vehicles times the time needed for the round trip between facilities (2* the number of transport days). In this example, 1250 round trips could be made over the five year life of the system. This provides a limit to the number of core engines that can eventually be integrated into the final launch vehicle. All calculations in this model are for the life of the system.

The maximum number of engines stored at production is the largest of the following:

- initial number stored at production,
- the size of the transportation batch,
- the total engines produced minus all engines shipped out.

The spreadsheet computes each of these quantities and then chooses the largest for the data entry. The high cost of maintaining these systems in storage as well as the large volume required for many of the bigger systems make the storage requirements a major concern . The total engines produced is the production rate times the number of production days. The other eight items all use the same formulas only with the particular data for that item input. The data from this part of the model defines the

production capabilities of the proposed system. These production rates can be compared to the production rates used in the previous LCC model described in Chapter 3. This gives the analyst the option of checking to see if the system can support the mission model and production rates assumed in the LCC calculations.

The bottleneck calculation computes the total production and compares it to the total transportation capability. A bottleneck occurs when production exceeds the transportation capability to send it to the next facility. The transportation requirements may seem trivial unless one considers the unique equipment that is required to move the various components. For instance, with the current Shuttle, a uniquely modified Boeing 747 aircraft performs the cross country retrieval from the western landing areas for return to the Cape. The loss of this aircraft could have major impacts on future schedules, cost and safety. These bottlenecks also indicate excess production that will increase storage requirements and costs at the production facility.

Transportation to Integration

Transportation requirements are analyzed in the next part of the module (N1-065) shown in Figure 22. This considers the number of transport vehicles, the capacity of each and the time needed to make the trip. This type of analysis provides the facility planner with information on transportation costs related to plant locations. It also considers what type of transport vehicles to use and what their capacity and rates should be. This data is presented in Figure 22. The first three items restate the input parameters discussed earlier. Transport batch size is how many items are contained in each batch shipment. The transport time to integration is how long the one-way trip takes between production and integration. The number of transports is how many

	N	O	P
1	TRANSPORTATION		DEL TO INTEG
2			
3	CORE ENG TRANSP		
4	TRNSPT BATCH SIZE	8	BOTTLENECK
5	TRNSPT TIME TO INTEG	1	2
6	# OF TRNSPT AVAIL	2	
7	MAX # OF SHIPMENTS	1250	
8	TOT # OF SHIPPED	250	

Figure 22. Transportation To Integration

transport vehicles the system has operating. The maximum number of engine shipments is the same data calculated in the production module. The total number shipped computes the minimum of either:

- the total produced plus initial engines at production or
- maximum number of shipments times the batch size.

The bottleneck calculation compares the total number of components integrated at the next station to the number initially shipped to integration. The bottleneck occurs if more are shipped in than can be integrated. From this result the analyst can decide if either the integration facilities need to be enlarged to handle the excess production or else production can be cut back.

Integration

The integration section of the module (Q1-V65) models three areas: component integration, system integration and bottlenecks. Component integration is defined as the integration of the components to form the booster, core or payload section. Vehicle integration is defined as the integration of the booster, core and payload section to form the final launch vehicle.

As an example, the core engine integration is shown in Figure 23.. The core engine section looks at the supply side of integration to determine input components and capability to store them. The first two items, the initial number at integration and storage capacity at integration, restate input parameters. The next item, maximum

	Q	R	T	U	V
1	BOOSTER INTEGRATION		VEHICLE INTEGRATON		
2					
3	CORE ENGINES		BSTR/CORE/AV/STRCT TIME	4	BOTTLENECK
4	INITIAL # AT INTEG	0	INIT # OF VEH @ INTEG	0	0
5	STOR CAP AT INTEG	40	VEH STOR CAP AT INTEG	5	
6	MAX # STORED	8	MAX # VEH STORED	1	
7	TOTAL INTEGRATED	248	MAX#RAW MATERIAL VEH	62	
8			MAX#POSS @INTEG TIME	312	
9			TOT # VEH PRODUCED	62	

Figure 23. Integration of Components

number stored, represents the balance between the number of items input and the output that is integrated. This number gives an indication of the needed storage capability due to a lack or slowing of the integration rate. It is computed as the maximum of:

- Initial * at integration
- * of transportation vehicles * the number per transportation batch
- Initial * at integration + total * shipped - Total * integrated.

The total number integrated is a function of integration rate and availability of required components. It is calculated as the number of complete components produced times the number of individual subcomponents per vehicle.

The first few items in the total vehicle integration column of Figure 23 restate the inputs for integration time, number of complete vehicles stored at integration and the vehicle storage capacity at integration. The maximum number of vehicles stored represents the maximum of:

- inputs minus outputs or
- transportation batch size or
- initial number in storage.

The maximum number of raw material vehicles is the number of complete vehicles that could be produced if all available materials could be utilized. This provides data that indicates how much raw material inventory is being carried relative to the actual integration rate. This means that vehicle production is limited by the sub-component in shortest supply. The maximum possible vehicle integration rate refers to the maximum that could be integrated based on the integration time per vehicle. This represents the maximum capability for the facility and is calculated as:

Max # of Veh Poss = (Total Number of Prod Days)/(Integ Rate per Day).

The actual number of vehicles integrated is the minimum of either:

- the raw material vehicle capability or
- the maximum possible integration capability.

The bottleneck section calculates excess integration capability over what can be shipped out to the launch site based on transportation capability. It is computed as the maximum of:

- 0
- Total integrated + initial # at integration - total sent to launch site.

The transportation capability required to move the finished vehicles to the launch pad is considered in the next module (W1-Z60) shown in Figure 24. The first three items, vehicle batch size, transport time to the launch site and number of vehicle transports available are repeated from the input section.

	W	X	Y
1	VEHICLE TRANSPORT		
2			
3	VEH BATCH SIZE TO LCH S	1	BOTTLENECK
4	TRANSPORT TIME TO SITE	12	0
5	*VEH TRANSP AVAIL	2	
6	MAX*VEH SHIPMENTS	104	
7	TOT* TRANSP TO SITE	62	

Figure 24. Transportation to Launch Site

The maximum number of shipments is computed the same as shown for the production section:

$$\text{Max Veh Shipments} = \text{Integer}\left(\frac{\dfrac{\text{Tot Number of Ops Days}}{2 * \text{Number of Trans Days}}}{\text{Number of Trans Veh}} \right)$$

The total number transported to the launch site is the minimum of:

- the total number integrated or
- the maximum number of shipments.

The bottleneck refers to shipments to the launch site in excess of launch rates. It is the maximum of:

- 0
- Total integrated + initial at integration - total transported to launch site.

Launch Operations

The launch operation results (Z1-AC60) are shown in Figure 25. Looking at the pre-launch column, the launch preparation time represents the time needed to make final preparations to the vehicle prior to launch. The activity time refers to the time for final actions needed to launch the finished vehicle. The initial vehicles at the pad shows the number of vehicles waiting to launch and the launch site storage refers to storage capability at the launch site. The maximum vehicles stored at the site relates the total number stored in excess of the launch rate.

The next group of data (row 6-16, columns A and B) is the total number of vehicle components used during the launches. The total expendable boosters consumed data refers to boosters that have used up all of their useful life and can not be reused. This is approximated as :

$$\text{Total Boosters Consumed (useful life)} = \frac{\text{(Tot Flts)* (Number of Bstrs per Flt)}}{\text{Booster Life}}$$

The number of booster engines is the number per booster times the number of boosters consumed. The total boosters recovered are computed as:

$$\text{Tot Bstrs Recovered} = \text{Tot Launches} * \text{Bstr/Veh} * \text{Number of Bstr Rec per Flt}$$

The final total boosters consumed is the total amount not recovered plus the number whose useful life expired:

$$\text{Total Boosters Consumed} = (\text{Tot Exp Bstr Cons})*\text{Numb Rec/Bstr per Flt} + \text{Numb of flt} * \text{Numb Lost per Flt}$$

The calculations for the core engines are similar. The total consumed was equal to the flight rate times the number of engines per core.

The payload results at the bottom of the first column restate some of the input data. The first three items refer to the initial number at the launch site and the storage capability. This model assumes one payload per flight so the total payloads launched was equal to the total launches.

Looking at the second column of data in Figure 25, the number of required boosters based on payloads and vehicles refers to the minimum number needed to fly the estimated number of flights assuming each met its expected lifetime. Launches based on hydrogen availability are computed as:

Launches based on H2 Avail = Avail H2/H2 per launch.

	A	B	C	D
1	PRE-LAUNCH		LAUNCH	
2				
3	LAUNCH PREP	6.5	BSTR REQD BASED ON PAYLDS	12
4	ACTIVITY TIME	2	BSTR REQD BASED ON VEHICLES	12
5				
6	INIT VEH AT SITE	0	#LCHS BASED ON H2 AVAIL	91
7	NEW VEH STOR CAPACITY	10	#OF POSS LAUNCHES (DAYS)	147
8	MAX VEH STORED AT SITE	1	TOTAL #OF LAUNCHES	62
9	TOT BSTRs LAUNCHED	248		
10	TOT EXP BSTRS CONSUMED	12		
11	TOT EXP BSTR ENG CONSD	12	BOOSTER REFURB	
12	TOT EXP BSTR RECOVERED	186		
13	TOT BSTRS CONSUMED	71	REF BSTR STOR AT SITE	6
14	TOT BSTR ENG CONSUMED	71	REC/REF ACTIVITY TIME	12
15	TOT CORES CONSUMED	62	#OF RECOVERY TRANSP	1
16	TOT CORE ENG CONSUMD	248	TOT#BSTR RECOVERIES	186
17				
18	PAYLOADS		HYDROGEN ACTIVITIES	
19	INIT#PYLDS @ LAUNCH SIT	0	INIT#H2@LAUNCH SITE	0
20	PYLD STOR CAP @ LCH SIT	1	H2 STOR CAP@LAUNCH SITE	6,000,000
21	MAX#PYLD STOR @ LCH SI	1	MAX H2 STOR@LAUNCH SITE	1,160,000
22	TOT#PYLD LAUNCHED	62	TOT H2 CONSUMED	71,920,000

Figure 25. Launch Operations

The number of possible launch days is the total operations days divided by the sum of pre-launch and launch rate times.

The final entries in the figure refer to the recovery effort needed to recover and refurbish the used boosters. It restates the input data for transportation vehicles, time needed to recover and storage capability. The total boosters recovered are calculated as the total launches time the boosters per vehicle times the recovery rate.

A summary of the bottlenecks and key outputs (Figures 26 and 27) is placed at the front of the spreadsheet (A40-I70). These tables contain the same data as presented

	A	B	C	D	E	F	G
1	BOTTLENECKS						
2	CORE ENG TRANSP		0		CORE ENG DEL TO INTEG		2
3	CORE STUCT TRANSP		0		CORE STRUCT DEL TO INTEG		0
4	CORE AVIONICS TRANSP		0		CORE AVIONICS DEL TO INTEG		0
5	BSTR ENG TRANSP		0		BSTR ENG DEL TO INTEG		2
6	BSTR STRUCT TRANSP		0		BSTR STRUCT DEL TO INTEG		2
7	BSTR AVIONICS TRANSP		0		BSTR AVIONICS DEL TO INTEG		2
8	PLATFORM TRANSP		0		PLATFORM DEL TO INTEG		0
9	FAIRING TRANSP		0		FAIRING DEL TO INTEG		0
10	HYDROGEN TRANSP		1,650,000				
11					VEH TRANS		0
12	VEH DEL TO PAD		0		PAYLOAD TRANS		0
13	PAYLOAD DEL TO PAD		0				
14	HYDROGEN DEL TO PAD		350,000				

Figure 26. Bottleneck Summary

in the network calculation module with these additions to the key output section shown in figure 27 :

Tot Bstr Costs = Tot Bstrs * Bstr Unit Costs

Tot Core Costs = Tot Cores * Core Unit Costs

Tot Payload to Orbit = Total Launches * 144,000

Yearly Payload to Orbit = Tot Payload to Orbit/Yrs of Ops

Shuttle Equiv Payloads = Integer(Tot Launched * 144,000/55,000)

Shuttle Equiv Cost = Shuttle Equiv Payloads * Shuttle Cost per Payload ($75M).

	A	B	C	D	E
35	OUTPUT RESULTS				
36					
37	# OF YEARS		5		
38	# OF PRODUCTION DAYS		1250		
39					
40	PRODUCTION				
41		TOT#PROD	TOT#SHIPPED	TOT#INTEG	STATUS
42	CORE ENGINES	250	250	248	CRITICAL
43	CORE STRUCT	62	62	62	CRITICAL
44	CORE AVIONICS	62	62	62	CRITICAL
45	BSTR ENGINES	250	250	248	CRITICAL
46	BSTR STRUCT	250	250	248	CRITICAL
47	BSTR AVIONICS	250	250	248	CRITICAL
48	PLATFORM	62	62	62	CRITICAL
49	FAIRING	62	62	62	CRITICAL
50	HYDROGEN	56,250,000	54,600,000	N/A	CRITICAL
51					
52	INTEGRATION				
53		TOT#PROD	TOT#TRANSP	TOT#LAUNCH	
54	VEHICLES	62	62	62	
55	PAYLOADS	62	62	62	
56	HYDROGEN	56,250,000	54,600,000	71,920,000	
57					
58		6			
59		NUMBER	COST		
60	BSTRS RECOV	186	$930,000,000		
61	TOT BSTRs LAUNCHE	248	$620,000,000		
62	TOT BSTRS CONSUME	71	$355,000,000		
63	TOT BSTR ENG CONS	71	$248,500,000		
64	TOT CORES CONSUM	62	$1,246,200,000		
65	TOT CORE ENG CONS	248	$843,200,000		

Figure 27. Output Summary

Model Summary

This infrastructure model provides the capability to look at the flow characteristics of an advanced production system and determine any bottlenecks in advance. Every time the inputs change, the model recomputes, so the output and

resulting changes are immediately known. This provides a relatively quick method of performing sensitivity analysis.

The model embodies several assumptions. As shown, there is no time dependent output. The model only considers the total life cycle as stated in the input section. The model shown is deterministic, so no delays or unexpected failures are modeled. All parameters remain constant for the entire lifetime. Recovered boosters are used before new boosters and recovered boosters are discarded after their predetermined life expires.

V. ANALYSIS RESULTS

This chapter shows the results of several representative types of analysis using the STARFLEET models. The chapter begins with a brief description of the types of analysis that can be done and some typical analysis categories. This is followed by a presentation of results derived from the baseline LCC model when used in a deterministic mode. The next part of the chapter shows how to perform sensitivity and stochastic analysis using the LCC model. The final section illustrates the use of the infrastructure model and its output.

STARFLEET Analysis

The LCC and Infrastructure spreadsheet models can be used to perform a variety of analyses. The models can be used to do either deterministic or stochastic analysis. In the deterministic mode, the inputs are varied to create a change in the output. With a modification to the baseline model, stochastic analysis can be performed to study the effect of randomness on the input parameters. Each of these methods is demonstrated in the following sections.

A variety of analysis questions concerning the ALS program can be answered by changing the input parameters. The following (Table 7) presents a partial list of typical analysis categories and the location of the input parameter that must be changed. The parameter coordinates refer to the location of the actual input in the spreadsheet model located in Appendix A. The analysis would be done by changing the input parameter of interest and noting the change in the output. This could be done using a range of values to determine the system sensitivity to the parameter.

Table 7. Analysis Categories and Respective Input Parameters

Categories of Analysis	Input Parameter
R&D	
Funding levels	R&D investment (I13-L36)
Funding duration	R&D investment (I13-L36)
Facility improvement costs	R&D investment (K13-K36)
Production	
Production improvements	LC/PC rates (A1-E7)
Reduced component costs	LC/PC rates (A1-E7)
	Init Costs (A17-D19)
Production rates	Flight Rate (AM13-AM36)
Operations	
Mission model changes	Flight Rates (AK13-AM36)
Operations costs	Ops Costs (U13-AA36)
Maintenance costs	Maint Costs (U13-U36)
Training programs	Training (Z13-Z36)
Launch site operations	ETR/WTR Ops (V13-W36)
Unreliability	
Reliability rates	Reliability rate (C23)
Cost penalties	Penalty factors (A24-C29)
Costing Effects	
Discount rates	Discount rate (D36-F36)

LCC Analysis

The first series of results uses the spreadsheet LCC model in a deterministic mode to determine the yearly costs of the proposed ALS system. The individual analysis is done by changing the input parameters to cause a change in the output. The input for this analysis is shown in Appendix A where the complete spreadsheet printout is

located. The inputs are contained in the input parameter module (A1-E19), the unreliability module (A22-F38), and the main costing modules (H12-AR36). The inputs describe a generic ALS vehicle and support system over a period of 22 years. The system is modeled from the start of research and development to the launching of the last production vehicles. This system is not intended to represent any actual proposed ALS system, but rather provide a reasonable data base for analysis. The mission model (see appendix A, AM22-AM36) is a generic one provided by the ALS office. The flights per year increase from an initial rate of 4 per year to a final rate of 30 per year over a period of 15 years and 336 flights.

Once all the data is input, the model provides the resulting life cycle costs. Figure 28 shows the standard spreadsheet output module as it appears on the computer screen. It contains a summary of the various costs and activities. The first part shows the total costs for the four main cost elements: R&D investment, production, operations and unreliability. These outputs are listed with and without their respective overhead rates. Moving downward, the net cost figures are shown in rows 8-10. These categories include cost per flight, cost per pound and total costs. The costs in the first column include the production, operations, and unreliability costs with the appropriate overhead rates applied for costs generated in the year in which a launch occurs. Columns E and F (rows 3-13) uses the same costs, but uses cumulative costs rather than yearly costs as the base. This means that the cost per flight and cost per pound are derived by dividing the total cumulative costs by the total cumulative flights or total cumulative payloads. These costs represent the definition that the ALS office uses when discussing a proposed system's expected costs. The cost per flight and total costs are in millions of dollars and the cost per pound is in actual dollars.

	A	B	C	D	E	F
1	OUTPUT SUMMARY					
2		BASE	W/OH			
3	INVEST	$12,485	$16,230		PLCC	$45,630
4	PROD	$17,485	$20,982		PLCC/FLT	$144
5	OPS	$2,053	$2,464		PLCC/LB	$999
6	UNREL	$5,955	$5,955			
7					TLCC	$45,630
8	COST/FLT	$58	$70		TLCC/FLT	$136
9	$/LB	$404	$538		TLCC/LB	$943
10	TOT COST	$37,977	$45,630			
11					T DISC LCC	$27,064
12	ETR FLTS	203			DISC/FLT	$81
13	WTR FLTS	133			DISC/LB	$926
14	TOT FLTS	336				
15	YEARS	22				
16						
17		LINEST	-181.39887	5062.28695		
18		LOGEST	0.90336137	6615.52193		
19						
20		ACT FLTS	COST/LB	PRED COST	PRED COST	
21			ACTUAL	LINEST	LOGEST	
22	1996	4	$6,157	$4,337	$4,406	
23	1997	12	$1,485	$2,886	$1,954	
24	1998	20	$721	$1,434	$867	
25	1999	20	$682	$1,434	$867	
26	2000	21	$651	$1,253	$783	
27	2001	22	$627	$1,072	$707	
28	2002	23	$608	$890	$639	
29	2003	24	$591	$709	$577	
30	2004	25	$562	$527	$521	
31	2005	25	$567	$527	$521	
32	2006	26	$556	$346	$471	
33	2007	27	$546	$165	$425	
34	2008	28	$537	($17)	$384	
35	2009	29	$528	($198)	$347	
36	2010	30	$166	($380)	$314	

Figure 28. STARFLEET Mission Model Output Section

On the right side of the output section are two more categories of LCC (E3-F13). These represent different ways of calculating LCC. The first, TLCC, refers to the total LCC which includes all R&D investments, production, operations and unreliability costs for the total program. These costs are computed using cumulative data for each year.

Discounted life cycle costs (DLCC) is computed like TLCC, but uses discounted yearly costs based on the input discount rate. In this example the discount rate was 5%.

The spreadsheet has the built-in ability to perform linear regression. This type of capability provides the analyst with a linear cost model for the original system based on the results of the full LCC model output. This type of meta-model, if accurate, provides the cost estimator with a new method of determining system costs without having to run the full STARFLEET model. The data at the bottom of Figure 15 (A17-E36) is the output of a regression done using the spreadsheet's built in regression function. The input shown in the first two columns are the flights per year and the launch cost per pound based on this yearly flight rate. This data came from the full LCC model (see Appendix A: BC 22-36, AM 22-36). The first data, labeled LINEST, is the output from the spreadsheet's built-in linear regression function. The linear regression model based on this input is:

$$\text{Cost/lb} = \$5{,}062.287 - \$181.399 * \text{Yrly Flight Rate}$$

The output in column D is the predicted cost using this cost model based on the flight rate for the respective year. Figure 16 shows this data plotted along with the original STARFLEET data. The fit is not very good and does not provide any realistic predictive capability.

The second method, LOGEST, fits a second order model of the form:

$$Y = C * A^N$$

where N is the yearly flight rate. The resulting equation is:

$$\text{Cost/lb} = \$6615.522 * 0.903361^N$$

The predicted yearly costs using this model are in column E and plotted in Figure 29.

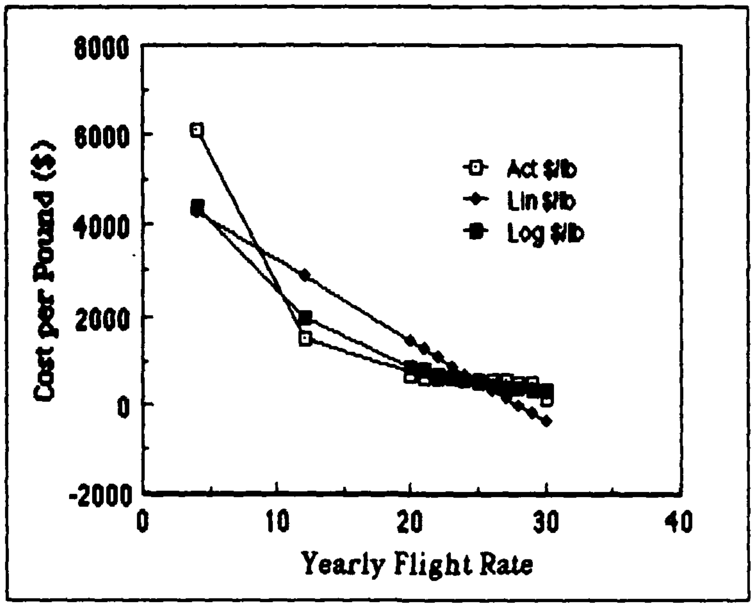

Figure 29. Regression Models for Launch Costs

Total Program Costs

Another area of interest concerns how the total costs spread out over the life of the program. Figure 30 shows a graph of the four main costs: R&D investment, production, operation and unreliability. The majority of the costs that occur during the first ten years are mainly due to the extensive investment in research and new facilities. Once the the production costs begin, they remain relatively high due to the stable demand for launch vehicles. The operational costs also remain stable since they are a direct function of the launch rate.

The unreliability costs are stable since they are a direct function of the launch rate. This model assumes that the failures and the associated costs are spread evenly over the life of the system on the basis of the yearly launch rate. These costs are included in the total LCC since they are expected to be incurred at some point during

the life of the system. In this particular example, a failure rate of 1% is assumed. This failure rate, which is lower than most current launch systems (6), represents over 20% of the total yearly costs during the operational life of the system. This indicates that investments in better system reliability might produce a large net cost savings.

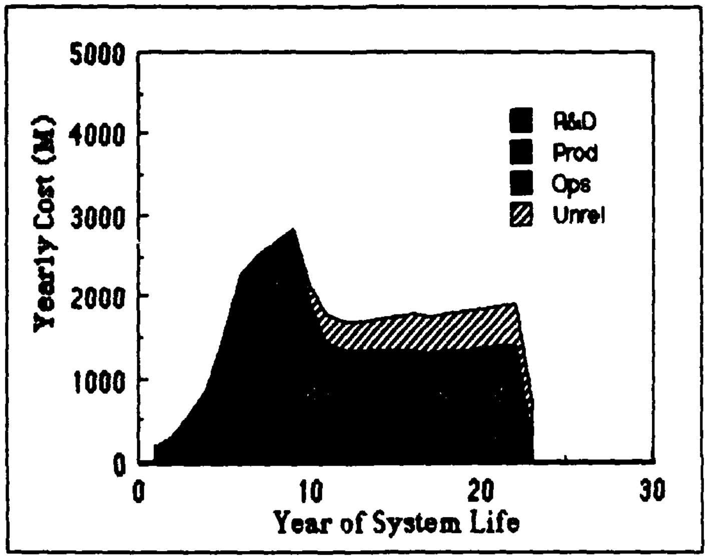

Figure 30. Major Cost Drivers of ALS

The main body of the spreadsheet (see Appendix A) contains all of the relevant input data and calculations that determine the cost of the launch vehicle system. The user may access any part of this data using the spreadsheet's graphics package to present a wide variety of figures and tables. The data can also be copied and transferred to other programs such as statistics, graphics or word processing packages.

Sensitivity Analysis

This next series of analyses looks at how to perform sensitivity analysis using the LCC spreadsheet model. Sensitivity analysis refers to looking at how key output parameters vary as the result of a change in an input parameter.

System Reliability Sensitivity

The first example analysis looks at the impact of system reliability. The analysis of various achieved reliability rates shows the expected costs due to failures, and therefore, the possible savings if they can be prevented. To begin the analysis, the desired inputs would be entered into the reliability calculation module shown in Figure 31. The user inputs the key cost parameters and estimates of penalties. In this example, the reliability rate will be varied over a range from 90-100% while all other inputs will remain constant. The reliability rate would be input in cells A2-C2. As the

	A	B	C	D	E
1	COST OF UNRELIABILITY				
2	REL RATE		0.99	# OF YEARS	15
3	DOWNTIME PENALTY		3.00	ETR FLIGHTS	0
4	MAX RECOVERY TIME		6.00	ETR PAYLOAD	144000
5	SURGE FRACTION		0.35	ETR LOADFACT	1
6	BACK LOG FRACTION		0.95	WTR FLIGHTS	0
7	PYLD COST/LB		$10,000	WTR PAYLOAD	107900
8	DOWNTIME COST		$50,000,000	WTR LOADFAC	1
9					
10	ETR NET LOAD	144,000	DOWNTIME ($M)		$504,000,000
11	WTR NET LOAD	107,900	PL LOSSES		$4,105,570,000
12	# OF FAILURES	3.36	TOT LOSSES		$5,759,129,600
13	YRS SYS DOWN	0.84	TOTAL/FLT		$17,140,267
14	# FLTS MISSE	19			
15	FTLS UNFLOWI	1	DISCOUNT RATE		5%
16	TOT PYLD UNF	114,956			
17	LOST VALUE	$1,149,559,600			

Figure 31. Reliability Cost Results for 99% Reliability Rate

Table 8. System LCC as a Function of Expected Reliability

Reliability Rate	Cost/lb	TLCC	DISC LCC
	$	$B	$B
1.0	820	39.6	24.3
.99	943	45.6	27.0
.98	1066	51.6	29.8
.97	1189	57.5	32.6
.96	1312	63.4	35.4
.95	1435	69.4	38.1
.94	1558	75.4	40.8
.93	1681	81.4	43.6
.92	1805	87.3	46.4
.91	1928	93.2	49.2
.90	2107	99.2	51.9

rate is manually changed, the costs are recomputed and then transferred to the unreliability costing module (Appendix A: AE13-AE38) of the main yearly cost module. The results are shown in Table 8. As expected, higher levels of reliability decrease expected system LCC. The changes in total LCC cost indicate the amount of cost that can be saved by increasing system reliability. This change also serves as an estimate of the reliability investment that might be made to develop the increased system reliability. For instance, assuming the ALS system currently achieves 96% reliability and the desired rate is 98%, then an investment of up to $11.8B might be appropriate to attain the new level. However, the cost of obtaining very high levels of reliability may prove extremely expensive compared to the level of cost savings (18). To obtain increases in reliability, investments must be made in research and development, production technology and system operations.

Table 9. Analysis of Proposed Production Improvement

	Original	Proposal
Investment	\$100M (additional)	\$0
Stage 1 1rst Cost	\$47.8M	\$42M
Stage 2 1rst Cost	\$102.7M	\$92M
Shroud 1rst Cost	\$21.6M	\$20M
Net Cost/lb (no OH)	\$404	\$387
TLCC	\$45.6B	\$44.8B
Disc LCC (5%)	\$27.0B	\$26.6B

Impact of New Production Facilities

This section includes an examination of the impact of an investment in new production facilities (Table 9). As an example, assume the contractor claims that an initial investment of \$100M in new equipment will decrease LCC significantly. For this example, the baseline case shown in Appendix A is used. The input for the non-recurring production investment (Appendix A: L13-L36) is increased by an additional \$100M spread over an assumed period of three years. To finish the inputs, assume the cost savings will come from a reduced first unit cost of the major vehicle components. The unit costs are decreased approximately 10% for stage 1, stage 2 and the shroud (Appendix A: A17-D19). The inputs and outputs of the analysis are summarized in Table 19. There is a slight savings of \$800M in undiscounted LCC or \$400M in discounted costs with this new investment. This relatively small amount is in the noise level (1.5% of orig TLCC) compared to the magnitude of the TLCC and DLCC. Also, this does not consider other possible uses of the investment funds that might produce greater benefits elsewhere. Based on this preliminary analysis, the proposed investment does not appear to produce substantial savings compared to its cost.

Learning and Production Factor Sensitivity

This analysis example considers the estimates for the production and learning curve effects. As with most of the LCC inputs, the learning curve and production curve parameters are based on historical data or best estimates that may not be relevant to the new system. The question to be answered is how sensitive will the final total LCC costs be to minor errors in estimating these factors. This example starts with the baseline case shown in Appendix A. The learning and production curve factors for stage 1 only are varied from 85% to 100%. The results of this analysis are shown in Table 10. The LCC does drop as the factors decrease as expected. These changes in LCC indicate that errors in estimating these rates by as little as 5% can change TLCC by $2B to $11.4B. The results show that if initial rates are low (near 100%), significant savings are possible through investments to improve the production process. However, if the learning and production rates are high already (near 85%), then the savings are relatively small ($1B) compared to the total costs and the probable investment needed to produce the new rates.

Table 10. Cost Sensitivity to Learning Curve and Production Factors

Input Rate	Cost/lb ($)	Tot LCC	Disc LCC
100%	$599	$57.0B	$32.5B
95%	$404	$45.6B	$27.1B
90%	$324	$40.9B	$24.8B
85%	$289	$38.9B	$23.7B

Discount Rate Sensitivity

This analysis considers the impact that the choice of discount rates has on the output. The discount rate used in many past government studies has ranged from 5-10%. However, outside organizations or contractors often use whatever discount rate makes their system look the best. This example uses the baseline data (Appendix A) and varies the discount rate from 2.5% to 10.0% while keeping all other inputs fixed. The results are shown in Table 11. The higher the discount rate the smaller the total discounted costs appear. This is caused by the decreasing value of the future costs. These results are not unexpected, but do illustrate the impact that a careful choice of discount rate can have on improving the DLCC of a proposed system. High discount rates tend to make programs with high costs at the end of the program look better than ones with high costs in the early stages. Figure 32 shows how the costs near the end of the program have less impact when discounted than those at the start (5% discount rate).

Table 11. Impact of Discount Rate on LCC Results

Discount Rate	Undisc TLCC	Disc TLCC	Disc TLCC/lb
2.5%	$45.6B	$34.7B	$1187
5.0%	$45.6B	$27.1B	$926
7.5%	$45.6B	$21.6B	$738
10.0%	$45.6B	$17.6B	$601
12.5%	$45.6B	$14.5B	$497
15.0%	$45.6B	$12.2B	$418
17.5%	$45.6B	$10.4B	$357
20.0%	$45.6B	$9.0B	$308

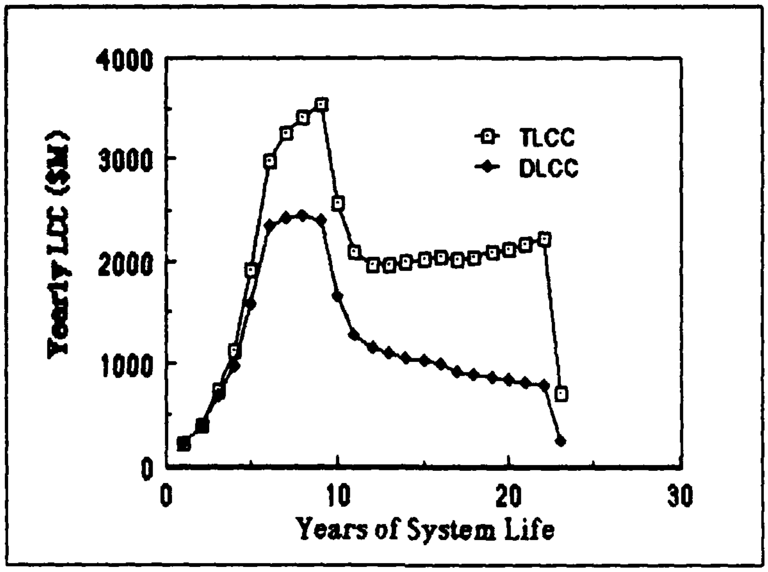

Figure 32. Impact of Discount Rate on LCC

Stochastic Modification of Mission Model

The LCC model seen so far has operated in a deterministic mode. That means that all results were derived from constant input parameters using analytical models. The model can be modified to use random inputs derived from predetermined distributions. A main area of interest concerns the mission flight rate model. The real system will suffer random failures and delays that will have a direct impact on cost. These costs may or may not be adequately predicted when using a constant input flight rate model. Other areas of concern would be investment costs, production rates, operational capabilities and unexpected funding changes. These occurrences could all be modeled using a predetermined distribution that would simulate the randomness of the exact event occurring.

The actual modifications to the analysis tool will be demonstrated using an example spreadsheet model shown in Figure 33 and contained in Appendix B. The general methodology would be as follows:

1. Determine the input(s) to be modeled stochastically.
2. Determine the actual or expected distribution of the input's values. This would come from historical data or system projections.
3. Modify the LCC model to perform the stochastic analysis.
   a. Insert the random number generator (spreadsheet function).
   b. Insert the distribution generator into the model at the appropriate location for the input parameter.
   c. Create the needed spreadsheet macro to generate multiple runs and to aggregate the results from the full LCC analysis.

Before looking at the actual input screen, an example using the methodology will provide a better understanding of the inputs and outputs. The rules listed here are just an example set created for this analysis.

1. For each year, generate a random number on U(0,1).
2. Compare the random number to the input distribution to determine the outcome .

If $U < 0.1$	Catastrophic Failure
If $U > 0.85$	Delay
else	normal operations

3. This outcome determines the actual flight rate for that period based on several considerations:

   a. If a failure occurs, no flights that period and the next period's flight rate is cut in half.

   b. If a delay occurs, the flight rate is reduced by one flight that period.

   c. A revised Flight rate schedule is created based on the previous penalties. This takes into account flights delayed into the following years and flight rate reductions predicated by failures in the previous year.

   d. A running count is kept showing total flights achieved vs. the new revised schedule.

   e. If a backlog occurs, the *flight rate may increase* up to 1/3 of the rate shown in the revised schedule. Surging is not allowed in years in which delays occur, failures occur or failure penalties occur.

4. Based on these calculations, the new mission flight rate model is created.

At this point, the new mission model represents one sample from a population. This new stochastic model needs to be run a sufficient number of times to obtain a desired confidence interval. The actual number of replications is based on the statistical precision required for the confidence interval of the output measure.

The example analysis uses the previous methodology to determine the flight rates. The system costs will be computed using a simple cost model:

$$\text{Cost per Year} = \$390/\text{lb} * \text{Total Lbs per year} + \$100\text{M each Year}$$

This provides a variable and fixed cost relationship to predict launch costs. In addition, the model applies penalty costs of $750-1000M for each failure and $10-25M for each delay. The penalties change depending on the year of the occurrence. This computes a cost per pound that can be compared to the original projected costs based on a fixed input flight rate projection.

A brief overview of the model shown in Figure 33 will demonstrate the flow of the calculations. The model works as follows:

1. Random numbers are generated for each year of the mission model. (B3-B18)
2. Based on this random number and the input distribution, the outcome of either a delay, failure or normal operations is determined. (C25-D39)
3. Based on this outcome, the actual number of flights are determined. (E24-E39)
4. Based on the actual number of flights, the revised flight rate (D4-D18), the backlog (G4-G18) and the surge capacity (B25-B39) are computed.
5. Using the actual flight rate data (E24-E39) and the disaster/delay information (C25-D39), the system costs are determined.

Looking at Figure 22, the first column (B3-B18) contains the random numbers that EXCEL provides. The random number draw changes each time a spreadsheet operation occurs. Column C contains the fixed projected flight rate that the user inputs. The revised flights (D4-D18) represent the new flight rate projections based on the random draw results. Columns E and F provide cumulative totals of the flight rates for use in future calculations.

	A	B	C	D	E	F	G
1	YEAR	RAND NUMB	PROJ FLTS	REVISED FLTS	CUM PROJ	CUM REVISED	BACKLOG
2							
3	1993	0.17					
4	1994	0.66	4	4	4	4	0
5	1995	0.34	12	12	16	16	0
6	1996	0.85	20	20	36	36	0
7	1997	0.18	20	20	56	56	0
8	1998	0.81	21	21	77	77	0
9	1999	0.81	22	22	99	99	0
10	2000	0.74	23	23	122	122	0
11	2001	0.51	24	24	146	146	0
12	2002	0.72	25	25	171	171	0
13	2003	0.09	25	25	196	196	0
14	2004	0.92	26	13	222	209	25
15	2005	0.40	27	27	249	236	38
16	2006	0.42	28	28	277	264	38
17	2007	0.45	29	29	306	293	38
18	2008	0.33	30	30	336	323	38
19							
20	TOT		336	323			
21							
22	YEAR	SURGE CAP	DISASTER	DELAYS	ACT FLTS	CUM ACT FLTS	
23							
24	1993						
25	1994	1	0	0	4	4	
26	1995	4	0	0	12	16	
27	1996	6	0	0	20	36	
28	1997	6	0	0	20	56	
29	1998	7	0	0	21	77	
30	1999	7	0	0	22	99	
31	2000	7	0	0	23	122	
32	2001	8	0	0	24	146	
33	2002	8	0	0	25	171	
34	2003	0	1	0	0	171	
35	2004	0	0	1	13	184	
36	2005	9	0	0	27	211	
37	2006	9	0	0	28	239	
38	2007	9	0	0	29	268	
39	2008	10	0	0	30	298	

Figure 33. Input and Analysis Section of Stochastic Flight Rate Generator

The backlog column (G4-G18) represents the number of backlogged flights in a given year as a result of delays or failures. The disaster and delay columns (C25-D39) list the outcome of the random number draw. A one indicates that a delay or failure occurred and a zero indicates no delay or failure In this case delays occur in the year 2004 while failures happen in the year 2003. Based on these delays and failures, a backlog begins in 2004 (year of delay) and runs through the end of the system's life. The actual flights represent the total of the revised flights and surge flights flown to meet the schedule and to try and reduce the backlog. This output represents just one sample, so this would need to be repeated many times.

Figure 34 shows the cost model used in this example to provide insight into the cost impact of the schedule fluctuations. The delay and disaster costs are computed as a fixed cost times the number of delays or failures. The operations cost is based on the

	A	B	C	D	E	F	G
44	YEAR	DELAY COST	DISASTER C	OPER COST	CUM COST	ACT FLTS	COST/LB
45				$M	$M		CUM
46	1993						
47	1994	0	0	$325	$325	4	$564
48	1995	0	0	$774	$1,099	12	$477
49	1996	0	0	$1,223	$2,322	20	$448
50	1997	0	0	$1,223	$3,545	20	$440
51	1998	0	0	$1,279	$4,824	21	$435
52	1999	0	0	$1,336	$6,160	22	$432
53	2000	0	0	$1,392	$7,552	23	$430
54	2001	0	0	$1,448	$8,999	24	$428
55	2002	0	0	$1,504	$10,503	25	$427
56	2003	0	750	$100	$11,353	0	$461
57	2004	10	0	$830	$12,193	13	$460
58	2005	0	0	$1,616	$13,810	27	$455
59	2006	0	0	$1,672	$15,482	28	$450
60	2007	0	0	$1,729	$17,211	29	$446
61	2008	0	0	$1,785	$18,996	30	$443

Figure 34. Costing Section for Stochastic Example

method discussed earlier. The cumulative cost is just the running total of the operation costs plus the penalty costs. The cumulative cost per pound is the cumulative total cost each year divided by the yearly cumulative total pounds of payload launched. This example assumes each payload is 144,000 pounds.

A spreadsheet macro performs the needed replications to create the sample population. The macro copies the specified results, pastes them in another part of the spreadsheet, then returns to obtain new data. The operation of copying data and pasting it elsewhere causes EXCEL to redo the random number draw and therefore provide a new set of results. The macro does this a specified number of times based on user input data. The final results shown in Figure 35 are based on a sample size of 10. The population mean of the yearly actual flight rates (D27-D41) is well below the

	A	B	C	D	E	F	G
24		PROJ FLTS	PROJ $/LB	ACT FLT AVE	ACT FLT SD	AVE COST/L	SD COST/LB
25	YEAR		CUM			CUM	
26	1993						
27	1994	4	564	3.2	1.79	$529	77.64
28	1995	12	477	10.6	2.61	$743	579.21
29	1996	20	448	16	8.94	$619	254.29
30	1997	20	440	13.8	8.79	$588	149.38
31	1998	21	435	19	5.05	$532	91.79
32	1999	21	428	22	0.00	$499	61.74
33	2000	23	427	18	10.07	$494	38.90
34	2001	24	425	21.6	5.37	$481	31.08
35	2002	25	424	20	11.18	$481	35.44
36	2003	25	423	14.8	13.52	$494	55.53
37	2004	26	423	20.6	6.95	$487	52.35
38	2005	27	422	21.8	12.19	$489	67.11
39	2006	28	421	25.2	6.26	$482	62.29
40	2007	29	420	23	12.86	$479	51.43
41	2008	30	420	21	13.42	$482	64.50
42							
43	TOTALS	335		270.6	7.93	$482	64.50

Figure 35. Result Section of the Stochastic Flight Rate Model

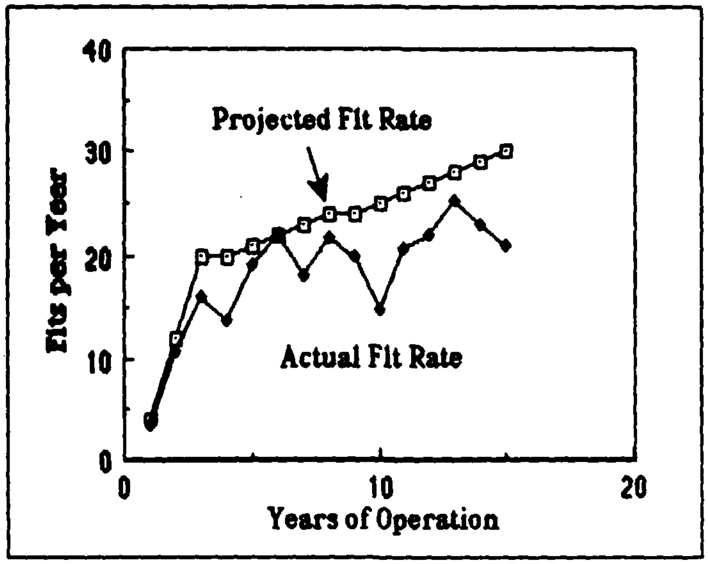

Figure 36. Actual vs Projected Flights Rates

initial yearly projected flight rates (B27-B41). This indicates that the failure rate (10%) and delays (15%) caused a significant loss of mission capability over the life of the system. A plot of this data (Figure 36) shows that the average actual flight rate (based on N = 10) fails to catch up to the initial projections even with a planned surge rate of 33%. This might indicate to the designer that either the system reliability must be increased or else surge capacity should be increased if the resulting backlogs are to be eliminated.

The cost per pound data (Figure 37) shows that the cost of the delays and failures can seriously impact the achieved system costs. Consider the cost of payloads such as the space telescope which has a multi-billion dollar price tag (approximately $3B). The loss of this one item when amortized over this study's generic mission model of 336 flights would add almost $9M per flight. Another factor to consider is the timing of the failures. A failure early in the flight program would have a much more

costly impact than one late in the program. Early failures might indicate a poor design or faulty flight operations. This would require an extensive investigation to determine the cause. If a problem was found, the solution may involve costly redesigning of the launch vehicle. A failure late in the program might be seen as a random failure or else down played since a new vehicle would probably be on the horizon as a replacement. The decision would possibly be made to invest money in the new vehicle and not to invest more money in a vehicle with a limited system life. This type of stochastic analysis could model these types of accidents. The cost estimating relationships would have to take into account the timing of the failures and delays. This might be done by using a power function similar to a learning curve. This would decrease the cost of future failures by some exponential factor compared to the initial cost of a first flight failure.

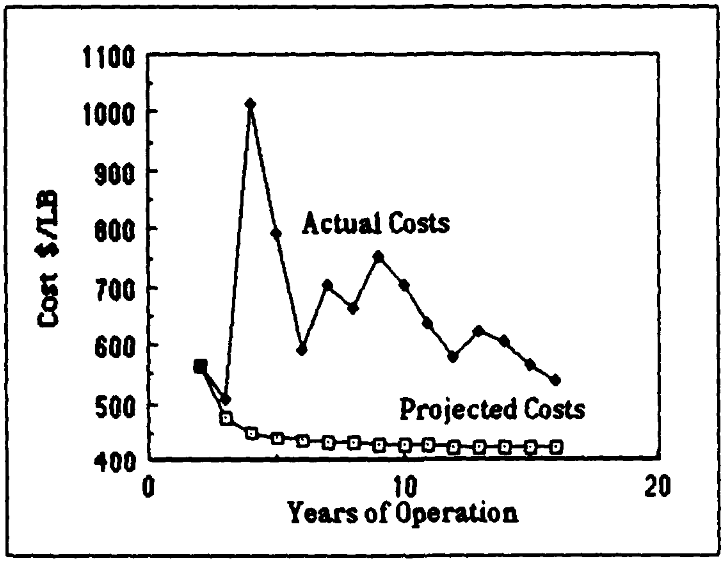

Figure 37. Actual vs Projected System Costs Using Stochastic Model

Cost Model Inserts

The last modification of the LCC model involves using a smaller cost model to arrive at total system costs. The involves replacing the cost module with an equation similar to:

$$\text{Yearly Cost} = \text{Fixed Cost} + N * \text{Variable Cost}$$

where N is the yearly flight rate. The cost models shown in Table 12 are available in the literature (6) and can be installed in the model. This involves removing the R&D investment, production, operations, and overhead modules from STARFLEET. These sections would be replaced with these linear cost models that would compute costs based on the mission model flight rate only. Cost models for proposed ALS systems can be obtained by running the full LCC model using normal input data and then forming a linear model using linear regression techniques. These reduced cost models allow the user to perform analysis using STARFLEET without requiring the input data for the full model.

TABLE 12. Current Yearly Launch Vehicle Costs

Vehicle	Commercial	Government	Reference Yr
Delta	24 + 23 N	36 + 26 N	(1984$M)
Atlas/Centaur	72 + 42 N	96 + 42 N	(1984$M)
Titan III	n/a	134.4 + 53 N	(1983$M)
Titan IV	n/a	127.2 + 57.8 N	(1983$M)
Shuttle	n/a	$1111 + 41.2\,N - 0.175\,N^2$	(1982$M)

Infrastructure Model

The infrastructure model looks at the system flow of launch assets as they travel from initial production facilities to the final launch sites. The types of analysis that this model performs involve balancing the flow of entities in the system and determining the actual rates for the various facilities. The analysis involves inputting all of the system characteristics and analyzing the results. The first example uses the input data presented in Chapter 4 and contained in Appendix C. This same baseline case was explained in detail in Chapter 4, so the reader is referred to that chapter for details concerning the analysis process of the model.

The baseline data for this example (Appendix C) describes an infrastructure containing production, integration and launch facilities needed for a two-stage partially reusable vehicle. Table 13 shows the results section from the model organized similar to actual screen output. The top of the summary shows the user that the model ran for a simulated 5 year period containing 1250 work days.

The production data describes the production facility results. It lists the total number of components produced, how many are shipped to the next facility and how many are actually integrated. The status column indicates if the component was a critical item that limited the final number of launches. Some items such as the booster components are critical since all available production is consumed. Others, such as the core structures and avionics, exceed the amount needed for integration requirements by a factor of two. To a system designer, this might indicate that these facilities are too large and could be reduced. The results also show that the booster component production is a bottleneck that will limit integration output. Notice that the model results indicate that more hydrogen is produced than could be shipped. This indicates either excess production or a lack of sufficient transportation capability exists.

Table 13. Summarized Output Results

# OF YEARS		5		
# OF PRODUCTION DAYS		1250		

PRODUCTION

	TOT#PROD	TOT#SHIPPED	TOT#INTEG	STATUS
CORE ENGINES	125	125	124	CRITICAL
CORE STRUCT	75	75	31	EXCESS
CORE AVIONICS	75	75	31	EXCESS
BSTR ENGINES	125	125	124	CRITICAL
BSTR STRUCT	125	125	124	CRITICAL
BSTR AVIONICS	125	125	124	CRITICAL
PLATFORM	43	43	31	EXCESS
FAIRING	31	31	31	CRITICAL
HYDROGEN	47,500,000	46,800,000	N/A	EXCESS

INTEGRATION

	TOT#PROD	TOT#TRANSP	TOT#LAUNCH
VEHICLES	31	31	31
PAYLOADS	31	31	31
HYDROGEN	47,500,000	46,800,000	35,960,000

	NUMBER	COST
BSTRS RECOV	93	$465,000,000
TOT BSTRs LAUNCHED	124	$620,000,000
TOT BSTRS CONSUMED	35	$175,000,000
TOT BSTR ENG CONSUM	35	$122,500,000
TOT CORES CONSUMED	31	$623,100,000
TOT CORE ENG CONSUM	124	$421,600,000

TOT PAYLOAD TO ORBIT	4,464,000 lbs
YEARLY PYLD TO ORBIT	892,800 lbs

The middle section of Table 13 lists the results from the integration module. Integration models the facilities that combine the subsystems (core, structures and avionics) into individual core vehicles and boosters. The system is able to launch all available vehicles coming out of integration. This indicates that the current capability is adequate, but does not provide an indication whether this rate is sufficient to handle all future needs. Note that the hydrogen shipped to the launch site exceeded the actual

demand. This indicates that not only was hydrogen production excessive based on demand, but that hydrogen transportation is sufficient to handle this type of launch activity.

Booster usage results are shown at the bottom of the table. In this model scenario, the boosters are recovered after launch and refurbished. The boosters have a limited service life as well as a chance of not being recovered. The vehicles in this example use four boosters per vehicle, have a service life of 20 uses and a 75% recovery rate per flight. Over the life of the system (31 launches), 93 out of 124 boosters are recovered and 35 boosters use up their service life. The costs for boosters and core vehicles are computed as the unit cost times the number of items used. The last items in Table 13 provide additional information in terms of yearly and lifetime payload delivered to orbit.

The analyst would use the model in the above manner to validate initial infrastructure system capabilities based on a given system proposal. This allows the user to determine if the proposed system has the capability to provide sufficient launch vehicles to meet the requirements of a given mission model. Analysis of the model results could identify potential bottlenecks due to insufficient production or integration capabilities. It also can help identify excessive production or transportation system capability.

The model can be used to perform sensitivity analysis on input parameters. This type of analysis requires the user to change the inputs and note the change in the output. As an example, consider the impact of varying the recovery factor for boosters. For each mission, a given number of boosters are assumed to be recovered. This number of recovered boosters can be varied from total recovery each flight to the total loss of all boosters each flight. For this example, the baseline spreadsheet in Appendix C is used. The production rate will be kept constant and the system will

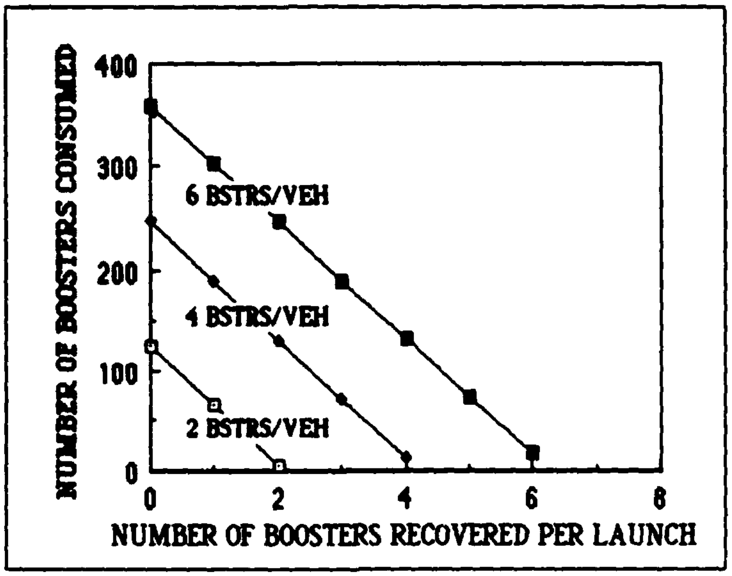

Figure 38. Booster Recovery Rate vs Boosters Consumed

produce 62 launch vehicles over five years. The example will model vehicles using two, four and six boosters with recovery rates from all to none of the boosters. Figure 38 shows the results of the multiple runs. The higher the recovery rate the fewer boosters are consumed during the life of the system. This provides the system manager with a way of estimating booster requirements based on recovery rates. The data also indicates that an investment in improving recovery rates may provide cost savings if the boosters are quite expensive compared to the recovery cost.

The infrastructure model may be used to look at the impact of increased production on the transportation system. For example, increasing production rates eventually will exceed the transportation capability. An analysis of the baseline data (Appendix C) is shown in Table 14. If the production rate increases beyond the levels shown, the connecting transportation system capacity will be exceeded. This analysis

was performed by increasing the production rate until a bottleneck occurred due to a lack of sufficient transportation capacity. All other inputs remained constant.

Table 14. Production Rates that Exceed Input Transportation Capabilities

	Production Rate
Core	
Engines	8/day
Structures	.5/day
Avionics	.5/day
Booster	
Engines	8/day
Structures	.5/day
Avionics	.5/day
Platforms	1/day
Fairings	.5/day

VIII. Conclusions and Recommendations

Value of the Model

The models developed for this thesis met the objectives of the study. They are relatively easy to use and require a *minimum of training for* office personnel to learn. The input data requirements are minimal and use data normally available in most contractor proposals. These features make the model a good tool to use for first cut analysis on new proposed launch systems. The real value of this type of analysis tool is the flexibility of the model to meet the requirements of a particular problem or launch system.

This effort demonstrates how a spreadsheet format can be used to implement the relevant details of the proposed ALS into an analysis framework. The particular model presented here was a baseline system that can be modified to simulate other launch systems. The model successfully meets the objectives concerning its required capabilities:

1. Provides a baseline for project direction.
2. Shows input parameters and their impact on output parameters.
3. Provides capability to perform deterministic sensitivity analysis.
4. Provides the capability to perform limited stochastic costing analysis of input systems.
5. Functions as a top level model.
6. Demonstrates an audit trail of costs for the input system.
7. Demonstrates the operational flow of the proposed ALS infrastructure.

Future Study

There are some areas of the model that warrant further improvement. The use of macros to provide easier access to all parts of the model can be developed to a greater extent. The individual cost modules can be expanded to provide greater detail of pertinent cost parameters. The model could be transferred to an MS-DOS spreadsheet program to take advantage of other possible spreadsheet capabilities.

The model could be expanded to handle a more complicated scenario. The number of systems could be increased to handle a variety of expendable and reusable vehicles that would make up the United States launch fleet. These vehicles would then be used to service a mission model composed of a multitude of satellites and other payloads. This would provide a more detailed look at total launch costs for the country's launch programs. In addition, this would allow the analyst to perform sensitivity analysis on the vehicle mix and flight rates to study the most efficient force structure. Another area would be to modify the model to provide estimates of launch requirements for future systems that would require deployment.

A major area that could be analyzed using this tool is the cost of unreliability. Major vehicle design questions are based on the trade-off between achieved reliability and the cost of obtaining this reliability. This model could be used in a stochastic mode to study the cost of possible failures as they occur during a system's life. This would provide the decision maker with a baseline to determine how much investment in reliability improvement is justified based on the expected cost of failure.

There are several areas associated with this type of model that could be implemented in future studies. Air Force Studies and Analysis is interested in a similar type of tool that would model the space operations from the view of the satellite community (11). This decision analysis tool would model the acquisition of launch

vehicles to meet requirements for future satellite systems as a function of required deployment schedules, payload launch requirements and cost.

The current model could be modified to implement a linear programming routine that would solve for optimal system designs using cost and schedule as objective functions. This would involve writing a large spreadsheet macro that would perform linear programming, or else find a commercial package and insert it into the model.

Decision support systems (DSS) and decision analysis techniques could be integrated with the model. For instance, a DSS shell could be developed that the model would be placed within. This would provide the user with a helpful environment that would allow access to needed data bases and analysis models. The model could be used as a costing algorithm or optimal fleet sizing tool to fit into a decision analysis model. The integration of all of these techniques would provide the decision maker with a powerful tool for studying proposed systems and how they could be used to meet Air Force space requirements.

The model could be also used as a prototype for a simulation program. The analyst would model several proposed systems using the current model and then choose the best one based on some predetermined criteria (lowest cost, highest flight rate, etc.). The best one would then be modeled in detail using a simulation model to investigate its response to a variety of stochastic inputs.

Appendix A. Listing of STARFLEET Mission Model Code Output

The first part of this section contains a printout of the model as it appears to the user on the computer screen. The particular output shown reflects the effect of the input data and would change significantly if that data were changed. The printout was made using the Print function and by highlighting appropriate areas of the spreadsheet to define the print area. The second printout shows the formulas in spreadsheet format for the individual cells. Details concerning these formulas are contained in Appendix D. The cells in the second printout correspond to the values shown in the first printout.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
12		OUTPUT SUMMARY								ALL AMOUNTS IN MILLIONS ($)				
13			BASE	W/OH					TECHNOLOG'	VEHICLE	FACILITIES	NR PROD	TOTAL INVESTMENT	
1														
2		INPUT PARAMETERS			RATE	FACTOR					RATE	FACTOR		COST OF UN
3	ETR OPS LC R	STG1 LEARNING CURVE RATE			0.950	-0.07400		ETR OPS LC RATE			0.900	-0.152		REL RATE
4	WTR OPS LC F	STG1 PROD CURVE RATE			0.947	-0.07856		WTR OPS LC RATE			0.900	-0.152		DOWNTIME P
5	SPARES USAE	STG2 LEARNING CURVE RATE			0.890	-0.16812		SPARES USAGE LC RATE			0.910	-0.136		MAX RECOVE
6	OPS PROJ MGT	STG2 PROD CURVE RATE			0.958	-0.06190		OPS PROJ MGMT LC RATE			0.930	-0.105		SURGE FRACT
7		SHROUD LEARNING CURVE RATE			0.900	-0.15200								BACK LOG FR
8	STAGE 1 INIT	SHROUD PROD CURVE RATE			0.940	-0.08927		STAGE 1 INITIAL COST			47.8			PYLD COST/L
9	STAGE 2 INIT	PROD PROJ MGMT LC RATE			0.930	-0.10470		STAGE 2 INITIAL COST			102.7			DOWNTIME CO
10	SHROUD INITI							SHROUD INITIAL COST			21.6			
11														
12		OUTPUT SUMMARY								ALL AMOUNTS IN MILLIONS ($)				
13			BASE	W/OH					TECHNOLOG'	VEHICLE	FACILITIES	NR PROD	TOTAL INVESTMENT	
14	1989	INVEST	$12,485	$16,230				1989	175.0	5.8			180.8	
15	1990	PROD	$17,485	$20,982				1990	154.9	46.2	122.0		323.1	
16	1991	OPS	$2,053	$2,464				1991	209.9	76.9	290.0		576.8	
17	1992	UNREL	$5,955	$5,955		Cumulative		1992	173.3	365.6	315.0		853.9	
18	1993		Net	Tot Yrly		TLCC	$45,630	1993	126.6	923.2	424.0		1473.8	
19	1994	COST/FLT	$58	$70		TLCC/FLT	$136	1994		1058.4	1242.0		2300.4	
20	1995	$/LB	$404	$538		TLCC/LB	$943	1995		1244.0	977.0	287.7	2508.7	
21	1996	TOT COST	$37,977	$45,630				1996		1095.20	776.0	287.7	2158.9	
22	1997					T DISC LCC	$27,064	1997		666.5	682.0	287.7	1636.2	
23	1998	ETR FLTS	203			DISC/FLT	$81	1998			414.0		414.0	
24	1999	WTR FLTS	133			DISC/LB	$926	1999			58.0		58.0	
25	2000	TOT FLTS	336					2000					0.0	
26	2001	YEARS	22					2001					0.0	
27	2002							2002					0.0	
28	2003							2003					0.0	
29	2004	LINEST	-181.3989	5082.287				2004					0.0	
30	2005	LOGEST	0.9033614	6615.5219				2005					0.0	
31	2006							2006					0.0	
32	2007	ACT FLTS	COST/LB	PRED COST	PRED COST			2007					0.0	
33	2008	4	6157	4337	4406			2008					0.0	
34	2009	12	1485	2886	1954			2009					0.0	
35	2010	20	721	1434	867			2010					0.0	
36	2011	20	682	1434	867			2011					0.0	
37		21	651	1253	783									
38	TOTAL	22	627	1072	707			TOTAL	839.7	5481.8	5300.0	863.1	12484.6	
39		23	608	890	639									
40		24	591	709	577									
41		25	562	527	521									
42		25	567	527	521									
43		26	558	346	471									
44		27	546	165	425									
45		28	537	-17	384									
46		29	528	-198	347									
47		30	166	-380	314									

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
12		RECURRING PRODUCTION						OPERATIONS					
13		STAGE 1	STAGE 2	SHROUD	PRJ MGT	TOTAL		FAC MAINT	ETR OPS	WTR OPS	TOT PROP	GSE SPARES	TRAINING
1													
2		RELIABILITY											
3	ETR OPS LC R		0.99		# OF YEARS		15		ETR NET LOA	144,000		DOWNTIME ($M)	
4	WTR OPS LC RIALTY		3.00		ETR FLIGHTS		133		WTR NET LOA	107,900		PL LOSSES	
5	SPARES USAEY TIME		6.00		ETR PAYLOAD		144,000		# OF FAILURE	3.36		TOT LOSSES	
6	OPS PROJ MGIION		0.35		ETR LOADFACTOR		1		YRS SYS DOW	0.84		TOTAL/FLT	
7		ACTION	0.95		WTR FLIGHTS		203		# FLTS MISSE	19			
8	STAGE 1 INIT3		$10,000		WTR PAYLOAD		107,900		FTLS UNFLOW	1		DISCOUNT RATE	
9	STAGE 2 INIT ST		$50,000,000		WTR LOADFACTOR		1		TOT PYLD UN	114,956			
10	SHROUD INIT1								LOST VALUE	$1,149,559,600			
11													
12		RECURRING PRODUCTION						OPERATIONS					
13		STAGE 1	STAGE 2	SHROUD	PRJ MGT	TOTAL		FAC MAINT	ETR OPS	WTR OPS	TOT PROP	GSE SPARES	TRAINING
14	1989												
15	1990												
16	1991												
17	1992												
18	1993												
19	1994												
20	1995												
21	1996	154.8	298.6	61.8	0.5	515.7							
22	1997	346.3	569.7	115.2	1.4	1032.6		69	7.2	5.9	4.8	3.3	0.8
23	1998	495.1	753.0	150.5	2.2	1400.8		69	9.7	7.2	14.4	8.6	2.4
24	1999	452.4	657.0	130.4	2.2	1242.0		69	11.6	8.7	24	13.3	4
25	2000	448.7	633.1	125.2	2.3	1209.3		69	11.6	8.7	24	13.3	4
26	2001	450.3	621.6	122.5	2.4	1196.8		69	12.0	8.7	25.2	13.9	4.2
27	2002	454.6	616.6	121.2	2.5	1194.9		69	12.0	9.0	26.4	14.4	4.4
28	2003	460.6	615.4	120.7	2.6	1199.3		69	12.4	9.0	27.6	15.0	4.6
29	2004	467.6	616.7	120.7	2.7	1207.7		69	12.4	9.4	28.8	15.6	4.8
30	2005	457.3	596.2	116.5	2.7	1172.7		69	12.9	9.4	30	16.1	5
31	2006	466.2	601.7	117.4	2.8	1188.2		69	12.9	9.4	30	16.1	5
32	2007	475.4	607.9	118.5	2.9	1204.7		69	13.3	9.4	31.2	16.7	5.2
33	2008	484.8	614.6	119.6	3.0	1222.0		69	13.3	9.7	32.4	17.2	5.4
34	2009	494.3	621.7	120.9	3.1	1239.9		69	13.7	9.7	33.6	17.8	5.6
35	2010	503.8	629.0	122.2	3.2	1258.2		69	13.7	10.1	34.8	18.3	5.8
36	2011	0.0	0	0	0	0.0		69	14.1	10.1	36	18.9	6
37													
38	TOTAL	6612.1	9052.9	1783.5	36.2	17484.6		1035	182.7	134.3	403.2	218.6	67.2
39													
40													
41													
42													
43													
44													
45													
46													
47													

	H	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM
12			TOTAL			99%								
13		PROJ MGMT	ANNUAL OPS		LCC	UNREL COST	TOTAL LCC		COST/FLT	$/lb AVE	AVE CAP	ETR FLIGHT	TOTAL FLT	FLT RATE
1														
2														
3	ETR OPS LC R	$504,000,000												
4	WTR OPS LC F	$4,105,570,000												
5	SPARES USAE	$5,759,129,600												
6	OPS PROJ MGI	$17,140,267												
7														
8	STAGE 1 INIT	58												
9	STAGE 2 INIT													
10	SHROUD INITI													
11														
12			TOTAL			99%								
13		PROJ MGMT	ANNUAL OPS		LCC	UNREL COST	TOTAL LCC		COST/FLT	$/lb AVE	AVE CAP	ETR FLIGHT	TOTAL FLT	FLT RATE
14	1989				180.8	0.0	180.8							
15	1990				323.1	0.0	323.1							
16	1991				576.8	0.0	576.8							
17	1992				853.9	0.0	853.9							
18	1993				1473.8	0.0	1473.8							
19	1994				2300.4	0.0	2300.4							
20	1995				2508.7	0.0	2508.7							
21	1996				2674.6	0.0	2674.6							
22	1997	0.2	91.2		2760.0	70.9	2830.9		$152	1053.7	0.13488	3	4	4
23	1998	0.5	111.7		1926.5	212.7	2139.2		$95	662.2	0.13197	8	16	12
24	1999	0.7	131.3		1431.3	354.4	1785.7		$77	532.0	0.12956	12	36	20
25	2000	0.7	131.3		1340.6	354.4	1695.0		$69	476.8	0.12956	12	56	20
26	2001	0.8	133.7		1330.5	372.2	1702.7		$64	444.1	0.13025	13	77	21
27	2002	0.8	136.1		1330.9	389.9	1720.8		$61	420.7	0.12923	13	99	22
28	2003	0.8	138.5		1337.8	407.6	1745.4		$58	402.6	0.12987	14	122	23
29	2004	0.9	140.8		1348.6	425.3	1773.9		$56	387.8	0.12896	14	146	24
30	2005	0.9	143.3		1315.9	443.0	1759.0		$54	375.3	0.12956	15	171	25
31	2006	0.9	143.3		1331.4	443.0	1774.5		$53	385.5	0.12956	15	196	25
32	2007	0.9	145.7		1350.4	460.8	1811.1		$51	356.3	0.13012	16	222	26
33	2008	1.0	148.0		1370.0	478.5	1848.5		$50	347.9	0.12929	16	249	27
34	2009	1.0	150.4		1390.3	496.2	1886.5		$49	340.4	0.12982	17	277	28
35	2010	1.0	152.7		1410.9	513.9	1924.8		$48	333.5	0.12906	17	306	29
36	2011	1.1	155.1		155.1	531.7	686.8		$47	327.1	0.12956	18	336	30
37					32022.3									
38	TOTAL	12.1	2053.1			5954.5	37976.8		$58	403.8	0.12971	205	336	336
39														
40														
41														
42														
43														
44														
45														
46														
47														

	N	AB	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB
12			TOTAL COSTS WITH OH						OPS+PROD				TOTAL LCC/YR	TOTAL LCC
13			TOT INV	PROD	OPS	UNREL		TOT COST	COST/FLT	$/lb				COST/FLT
1														
2														
3	ETR OPS LC R													
4	WTR OPS LC F													
5	SPARES USAE													
6	OPS PROJ MGI													
7														
8	STAGE 1 INIT													
9	STAGE 2 INIT													
10	SHROUD INITI													
11														
12			TOTAL COSTS WITH OH						OPS+PROD				TOTAL LCC/YR	TOTAL LCC
13			TOT INV	PROD	OPS	UNREL		TOT COST	COST/FLT	$/lb				COST/FLT
14	1989		235	0	0	0		235			1988		$235.04	$0.00
15	1990		420	0	9	0		420			1989		$420.03	$0.00
16	1991		750	0	0	0		750			1990		$749.84	$0.00
17	1992		1,110	0	0	0		1,110			1991		$1,110.07	$0.00
18	1993		1,916	0	0	0		1,916			1992		$1,915.94	$0.00
19	1994		2,991	0	0	0		2,991			1993		$2,990.52	$0.00
20	1995		3,261	0	0	0		3,261			1994		$3,261.31	$0.00
21	1996		2,807	619	0	0		3,425			1995		$3,425.46	$0.00
22	1997		2,127	1,239	109	71		3,546	182.1	1349.0	1996		$3,546.48	$886.62
23	1998		538	1,681	134	213		2,566	114.4	867.1	1997		$2,565.86	$213.82
24	1999		75	1,490	158	354		2,078	91.9	709.5	1998		$2,077.81	$103.89
25	2000		0	1,451	158	354		1,963	82.4	636.0	1999		$1,963.12	$98.16
26	2001		0	1,436	160	372		1,969	76.7	589.2	2000		$1,968.76	$93.75
27	2002		0	1,434	163	390		1,987	72.7	562.6	2001		$1,987.01	$90.32
28	2003		0	1,439	166	408		2,013	69.6	535.7	2002		$2,012.91	$87.52
29	2004		0	1,449	169	425		2,044	67.0	519.6	2003		$2,043.59	$85.15
30	2005		0	1,407	172	443		2,022	64.8	500.5	2004		$2,022.18	$80.89
31	2006		0	1,426	172	443		2,041	63.2	487.5	2005		$2,040.76	$81.63
32	2007		0	1,446	175	461		2,081	61.6	473.1	2006		$2,081.22	$80.05
33	2008		0	1,466	178	478		2,122	60.1	465.0	2007		$2,122.50	$78.61
34	2009		0	1,488	180	496		2,165	58.8	453.1	2008		$2,164.54	$77.31
35	2010		0	1,510	183	514		2,207	57.6	446.5	2009		$2,206.99	$78.10
36	2011		0	0	186	532		718	56.5	438.3	2010		$717.80	$23.93
37														
38	TOTAL		16,230	37,212	39,675	45,630		45,630	69.8	537.9			$45,629.76	$143.85
39														
40														
41														
42														
43														
44														
45														
46														
47														

	H	BC	BD	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN
12		TOTAL LCC	CUM TOT LCC	TOT AVE LC	TOT AVE LCC		DISCOUNT FACTOR		DISC OP C0	DIS OP COS	TOT LCC	TOT LCC	CUM TOT
13		COST/LB		COST/FLT	COST/LB		BASE YEAR = 1989		PER FLT ($	PER LB ($)	PER YEAR	PER FLT	DISC LCC
1													
2													
3	ETR OPS LC R												
4	WTR OPS LC F												
5	SPARES USAE												
6	OPS PROJ MGI												
7													
8	STAGE 1 INIT												
9	STAGE 2 INIT												
10	SHROUD INITI												
11													
12		TOTAL LCC	CUM TOT LCC	TOT AVE LC	TOT AVE LCC		DISCOUNT FACTOR		DISC OP C0	DIS OP COS	TOT LCC	TOT LCC	CUM TOT
13		COST/LB		COST/FLT	COST/LB		BASE YEAR = 1989		PER FLT ($	PER LB ($)	PER YEAR	PER FLT	DISC LCC
14	1989	$0.00	$235.04	$0.00	$0.00		1.000		0.00	0.00	235.04	0.00	235.04
15	1990	$0.00	$655.07	$0.00	$0.00		0.952		0.00	0.00	400.03	0.00	635
16	1991	$0.00	$1,404.91	$0.00	$0.00		0.907		0.00	0.00	680.13	0.00	1,315
17	1992	$0.00	$2,514.98	$0.00	$0.00		0.864		0.00	0.00	958.92	0.00	2,274
18	1993	$0.00	$4,430.92	$0.00	$0.00		0.823		0.00	0.00	1,576.25	0.00	3,850
19	1994	$0.00	$7,421.44	$0.00	$0.00		0.784		0.00	0.00	2,343.15	0.00	6,194
20	1995	$0.00	$10,682.75	$0.00	$0.00		0.746		0.00	0.00	2,433.64	0.00	8,627
21	1996	$0.00	$14,108.21	$0.00	$0.00		0.711		0.00	0.00	2,434.41	0.00	11,062
22	1997	$6,157.09	$17,654.70	$4,413.67	$30,650.52		0.677		123.24	913.06	2,400.40	600.10	13,462
23	1998	$1,484.87	$20,220.56	$1,263.78	$8,776.28		0.645		73.76	558.96	1,653.98	137.83	15,116
24	1999	$721.46	$22,298.37	$619.40	$4,301.38		0.614		56.43	435.57	1,275.60	63.78	16,392
25	2000	$681.64	$24,261.49	$433.24	$3,008.62		0.585		48.18	371.85	1,147.80	57.39	17,539
26	2001	$651.05	$26,230.25	$340.65	$2,365.64		0.557		42.73	328.10	1,096.28	52.20	18,636
27	2002	$627.21	$28,217.26	$285.02	$1,979.33		0.530		38.56	298.34	1,053.75	47.90	19,689
28	2003	$607.76	$30,230.17	$247.79	$1,720.75		0.505		35.14	270.54	1,018.66	44.20	20,706
29	2004	$591.32	$32,273.78	$221.05	$1,535.09		0.481		32.23	249.93	983.00	40.96	21,689
30	2005	$561.72	$34,295.95	$200.56	$1,392.79		0.458		29.71	229.29	926.39	37.06	22,615
31	2006	$566.88	$36,336.71	$185.39	$1,287.44		0.436		27.56	212.71	890.38	35.62	23,506
32	2007	$555.88	$38,417.93	$173.05	$1,201.78		0.416		25.58	196.80	864.79	33.26	24,371
33	2008	$545.91	$40,540.43	$162.81	$1,130.65		0.396		23.79	184.81	839.94	31.11	25,211
34	2009	$536.84	$42,704.97	$154.17	$1,070.62		0.377		22.17	170.76	815.79	29.14	26,026
35	2010	$528.49	$44,911.98	$146.77	$1,019.24		0.359		20.68	160.26	792.18	27.32	26,819
36	2011	$166.16	$45,629.76	$135.80	$943.08		0.342		19.33	149.16	245.38	8.18	27,064
37													
38	TOTAL	$998.95						TOTALS	619	315	1,177	83	27,064
39													
40													
41													
42													
43													
44													
45													
46													
47													

	B	C	D	E	F
1					
2	INPUT PARAMETERS			RATE	FACTOR
3	STG1 LEARNING CURVE RATE			0.95	=LN(E3)/LN(2)
4	STG1 PROD CURVE RATE			0.947	=LN(E4)/LN(2)
5	STG2 LEARNING CURVE RATE			0.89	=LN(E5)/LN(2)
6	STG2 PROD CURVE RATE			0.958	=LN(E6)/LN(2)
7	SHROUD LEARNING CURVE RAT			0.9	=LN(E7)/LN(2)
8	SHROUD PROD CURVE RATE			0.94	=LN(E8)/LN(2)
9	PROD PROJ MGMT LC RATE			0.93	=LN(E9)/LN(2)
10					
11					
12	OUTPUT SUMMARY				
13		BASE	W/OH		
14	INVEST	=M38	=C14*1.3		
15	PROD	=S38	=C15*1.2		
16	OPS	=AB38	=C16*1.2		
17	UNREL	=AE38	=C17		Cumulative
18		Net	Tot Vrly		TLCC
19	COST/FLT	=AH38	=AW38		TLCC/FLT
20	$/LB	=AI38	=AX38		TLCC/LB
21	TOT COST	=AF38	=AV38		
22					T DISC LCC
23	ETR FLTS	=AK38			DISC/FLT
24	WTR FLTS	=C25-C23			DISC/LB
25	TOT FLTS	=AM38			
26	YEARS	=H35-H14+1			
27					
28					
29	LINEST	=LINEST(BC22:BC36,AM22:AM36)	=LINEST(BC22:BC36,AM22:AM36)		
30	LOGEST	=LOGEST(BC22:BC36,AM22:AM36)	=LOGEST(BC22:BC36,AM22:AM36)		
31					
32	ACT FLTS	COST/LB	PRED COST	PRED COST	
33	=AM22	=BC22	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
34	=AM23	=BC23	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
35	=AM24	=BC24	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
36	=AM25	=BC25	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
37	=AM26	=BC26	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
38	=AM27	=BC27	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
39	=AM28	=BC28	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
40	=AM29	=BC29	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
41	=AM30	=BC30	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
42	=AM31	=BC31	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
43	=AM32	=BC32	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
44	=AM33	=BC33	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
45	=AM34	=BC34	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
46	=AM35	=BC35	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	
47	=AM36	=BC36	=TREND(BC22:BC36,AM22:AM36)	=GROWTH(BC22:BC36,AM22:AM36)	

	G	H	I	J	K	L	M
1							
2					RATE	FACTOR	
3		ETR OPS LC RATE			0.9	=LN(K3)/LN(2)	
4		WTR OPS LC RATE			0.9	=LN(K4)/LN(2)	
5		SPARES USAGE LC RATE			0.91	=LN(K5)/LN(2)	
6		OPS PROJ MGMT LC RATE			0.93	=LN(K6)/LN(2)	
7							
8		STAGE 1 INITIAL COST			47.8		
9		STAGE 2 INITIAL COST			102.7		
10		SHROUD INITIAL COST			21.6		
11							
12				ALL AMOUNTS IN			
13			TECHNOLOGY	VEHICLE	FACILITIES	RR PROD	TOTAL INVESTMENT
14		1989	175	=5.8			=SUM(I14:L14)
15		1990	154.9	=46.2	122		=SUM(I15:L15)
16		=H15+1	209.9	=76.9	290		=SUM(I16:L16)
17		=H16+1	173.3	=365.6	315		=SUM(I17:L17)
18	=BD36	=H17+1	126.6	=923.2	424		=SUM(I18:L18)
19	=BE36	=H18+1		=1058.4	1242		=SUM(I19:L19)
20	=BF36	=H19+1		=1244	977	287.7	=SUM(I20:L20)
21		=H20+1		=1095.2	776	287.7	=SUM(I21:L21)
22	=BN38	=H21+1		=666.5	682	287.7	=SUM(I22:L22)
23	=G22/C25	=H22+1			414		=SUM(I23:L23)
24	=1000000*G23/((C23*144000+G25*107900)/C25)	=H23+1			58		=SUM(I24:L24)
25		=H24+1					=SUM(I25:L25)
26		=H25+1					=SUM(I26:L26)
27		=H26+1					=SUM(I27:L27)
28		=H27+1					=SUM(I28:L28)
29		=H28+1					=SUM(I29:L29)
30		=H29+1					=SUM(I30:L30)
31		=H30+1					=SUM(I31:L31)
32		=H31+1					=SUM(I32:L32)
33		=H32+1					=SUM(I33:L33)
34		=H33+1					=SUM(I34:L34)
35		=H34+1					=SUM(I35:L35)
36		=H35+1					0
37							
38		TOTAL	=SUM(I14:I36)	=SUM(J14:J36)	=SUM(K14:K36)	=SUM(L14:L36)	=SUM(M14:M36)

	A	O	P
1			
2	COST OF UNRELIABILITY		
3	REL RATE		0.99
4	DOWNTIME PENALTY		3
5	MAX RECOVERY TIME		6
6	SURGE FRACTION		0.35
7	BACK LOG FRACTION		0.95
8	PYLD COST/LB		10000
9	DOWNTIME COST		50000000
10			
11			
12		RECURRING PRODUCTION	
13		STAGE 1	STAGE 2
14			
15			
16			
17			
18			
19			
20			
21		=K8*((AL22*AL22^F3*AL22^F4))	=102.7*((AL22*AL22^F5*AL22^F6))
22		=K8*((AL23*AL23^F3*AL23^F4)-(AL22*AL22^F3*AL22^F4))	=102.7*((AL23*AL23^F5*AL23^F6)-(AL22*AL22^F5*AL22^F6))
23		=K8*((AL24*AL24^F3*AL24^F4)-(AL23*AL23^F3*AL23^F4))	=102.7*((AL24*AL24^F5*AL24^F6)-(AL23*AL23^F5*AL23^F6))
24		=K8*((AL25*AL25^F3*AL25^F4)-(AL24*AL24^F3*AL24^F4))	=102.7*((AL25*AL25^F5*AL25^F6)-(AL24*AL24^F5*AL24^F6))
25		=K8*((AL26*AL26^F3*AL26^F4)-(AL25*AL25^F3*AL25^F4))	=102.7*((AL26*AL26^F5*AL26^F6)-(AL25*AL25^F5*AL25^F6))
26		=K8*((AL27*AL27^F3*AL27^F4)-(AL26*AL26^F3*AL26^F4))	=102.7*((AL27*AL27^F5*AL27^F6)-(AL26*AL26^F5*AL26^F6))
27		=K8*((AL28*AL28^F3*AL28^F4)-(AL27*AL27^F3*AL27^F4))	=102.7*((AL28*AL28^F5*AL28^F6)-(AL27*AL27^F5*AL27^F6))
28		=K8*((AL29*AL29^F3*AL29^F4)-(AL28*AL28^F3*AL28^F4))	=102.7*((AL29*AL29^F5*AL29^F6)-(AL28*AL28^F5*AL28^F6))
29		=K8*((AL30*AL30^F3*AL30^F4)-(AL29*AL29^F3*AL29^F4))	=102.7*((AL30*AL30^F5*AL30^F6)-(AL29*AL29^F5*AL29^F6))
30		=K8*((AL31*AL31^F3*AL31^F4)-(AL30*AL30^F3*AL30^F4))	=102.7*((AL31*AL31^F5*AL31^F6)-(AL30*AL30^F5*AL30^F6))
31		=K8*((AL32*AL32^F3*AL32^F4)-(AL31*AL31^F3*AL31^F4))	=102.7*((AL32*AL32^F5*AL32^F6)-(AL31*AL31^F5*AL31^F6))
32		=K8*((AL33*AL33^F3*AL33^F4)-(AL32*AL32^F3*AL32^F4))	=102.7*((AL33*AL33^F5*AL33^F6)-(AL32*AL32^F5*AL32^F6))
33		=K8*((AL34*AL34^F3*AL34^F4)-(AL33*AL33^F3*AL33^F4))	=102.7*((AL34*AL34^F5*AL34^F6)-(AL33*AL33^F5*AL33^F6))
34		=K8*((AL35*AL35^F3*AL35^F4)-(AL34*AL34^F3*AL34^F4))	=102.7*((AL35*AL35^F5*AL35^F6)-(AL34*AL34^F5*AL34^F6))
35		=K8*((AL36*AL36^F3*AL36^F4)-(AL35*AL35^F3*AL35^F4))	=102.7*((AL36*AL36^F5*AL36^F6)-(AL35*AL35^F5*AL35^F6))
36		0	0
37			
38		=SUM(O14:O36)	=SUM(P14:P36)

	Q	R	S	T	U	V
1						
2						
3		# OF YEARS		15		ETR NET LOAD
4		ETR FLIGHTS		=AL38-AK38		WTR NET LOAD
5		ETR PAYLOAD		144000		# OF FAILURES
6		ETR LOADFACTOR		1		YRS SYS DOWN
7		WTR FLIGHTS		=AK38		# FLTS MISSED
8		WTR PAYLOAD		107900		FTLS UNFLOWN
9		WTR LOADFACTOR		1		TOT PYLD UNFLN
10						LOST VALUE
11						
12					OPERATIONS	
13	SHROUD	PRJ MGT	TOTAL		FAC MAINT	ETR OPS
14						
15						
16						
17						
18						
19						
20						
21	=21.6*((AL22*AL22^T7*AL22^T8))	=0.75*0.2*($AM22*$AM22^T9)	=SUM(Q21:R21)			
22	=21.6*((AL23*AL23^T7*AL23^T8)-(AL22*AL22^T7*AL22^T8))	=0.75*0.2*($AM23*$AM23^T9)	=SUM(Q22:R22)		69	=5.3+(0.76*AK22^1.3)*AK22
23	=21.6*((AL24*AL24^T7*AL24^T8)-(AL23*AL23^T7*AL23^T8))	=0.75*0.2*($AM24*$AM24^T9)	=SUM(Q23:R23)		69	=5.3+(0.76*AK23^1.3)*AK23
24	=21.6*((AL25*AL25^T7*AL25^T8)-(AL24*AL24^T7*AL24^T8))	=0.75*0.2*($AM25*$AM25^T9)	=SUM(Q24:R24)		69	=5.3+(0.76*AK24^1.3)*AK24
25	=21.6*((AL26*AL26^T7*AL26^T8)-(AL25*AL25^T7*AL25^T8))	=0.75*0.2*($AM26*$AM26^T9)	=SUM(Q25:R25)		69	=5.3+(0.76*AK25^1.3)*AK25
26	=21.6*((AL27*AL27^T7*AL27^T8)-(AL26*AL26^T7*AL26^T8))	=0.75*0.2*($AM27*$AM27^T9)	=SUM(Q26:R26)		69	=5.3+(0.76*AK26^1.3)*AK26
27	=21.6*((AL28*AL28^T7*AL28^T8)-(AL27*AL27^T7*AL27^T8))	=0.75*0.2*($AM28*$AM28^T9)	=SUM(Q27:R27)		69	=5.3+(0.76*AK27^1.3)*AK27
28	=21.6*((AL29*AL29^T7*AL29^T8)-(AL28*AL28^T7*AL28^T8))	=0.75*0.2*($AM29*$AM29^T9)	=SUM(Q28:R28)		69	=5.3+(0.76*AK28^1.3)*AK28
29	=21.6*((AL30*AL30^T7*AL30^T8)-(AL29*AL29^T7*AL29^T8))	=0.75*0.2*($AM30*$AM30^T9)	=SUM(Q29:R29)		69	=5.3+(0.76*AK29^1.3)*AK29
30	=21.6*((AL31*AL31^T7*AL31^T8)-(AL30*AL30^T7*AL30^T8))	=0.75*0.2*($AM31*$AM31^T9)	=SUM(Q30:R30)		69	=5.3+(0.76*AK30^1.3)*AK30
31	=21.6*((AL32*AL32^T7*AL32^T8)-(AL31*AL31^T7*AL31^T8))	=0.75*0.2*($AM32*$AM32^T9)	=SUM(Q31:R31)		69	=5.3+(0.76*AK31^1.3)*AK31
32	=21.6*((AL33*AL33^T7*AL33^T8)-(AL32*AL32^T7*AL32^T8))	=0.75*0.2*($AM33*$AM33^T9)	=SUM(Q32:R32)		69	=5.3+(0.76*AK32^1.3)*AK32
33	=21.6*((AL34*AL34^T7*AL34^T8)-(AL33*AL33^T7*AL33^T8))	=0.75*0.2*($AM34*$AM34^T9)	=SUM(Q33:R33)		69	=5.3+(0.76*AK33^1.3)*AK33
34	=21.6*((AL35*AL35^T7*AL35^T8)-(AL34*AL34^T7*AL34^T8))	=0.75*0.2*($AM35*$AM35^T9)	=SUM(Q34:R34)		69	=5.3+(0.76*AK34^1.3)*AK34
35	=21.6*((AL36*AL36^T7*AL36^T8)-(AL35*AL35^T7*AL35^T8))	=0.75*0.2*($AM36*$AM36^T9)	=SUM(Q35:R35)		69	=5.3+(0.76*AK35^1.3)*AK35
36	0	0	=SUM(Q36:R36)		69	=5.3+(0.76*AK36^1.3)*AK36
37						
38	=SUM(Q14:Q36)	=SUM(R14:R36)	=SUM(Q38:R38)		=SUM(U22:U3	=SUM(V22:V36)

	W	X	Y	Z	AA	AB
1						
2						
3	=T5*T6		DOWNTIME ($M)		=W6*12*P9	
4	=T8*T9		PL LOSSES		=((T4*T5)*(1-P3)+(T7*T8)*(1-P3))*P8	
5	=(T4+T7)*(1-P3)		TOT LOSSES		=AA3+AA4+W10	
6	=W5*(P4/12)		TOTAL/FLT		=AA5/(T4+T7)	
7	=W6*(T4+T7)/T3					
8	=W7*(1-P7)		DISCOUNT RATE		0.05	
9	=W8*(T5*T4+T7*T8)/(T4+T7)					
10	=W9*P8					
11						
12						TOTAL
13	WTR OPS	TOT PROP	GSE SPARES	TRAINING	PROJ MGMT	ANNUAL OPS
14						
15						
16						
17						
18						
19						
20						
21						
22	=5.3+(0.58*(AM22-AK22)^.4)*(AM22-AK22)	=1.2*+AM22	=(AM22^.5)*AM22	=0.2*AM22	=0.25*0.2*($AM22*$AM22^-0.1047)	=SUM(U22:AA22)
23	=5.3+(0.58*(AM23-AK23)^.4)*(AM23-AK23)	=1.2*+AM23	=(AM23^.5)*AM23	=0.2*AM23	=0.25*0.2*($AM23*$AM23^.6)	=SUM(U23:AA23)
24	=5.3+(0.58*(AM24-AK24)^.4)*(AM24-AK24)	=1.2*+AM24	=(AM24^.5)*AM24	=0.2*AM24	=0.25*0.2*($AM24*$AM24^.6)	=SUM(U24:AA24)
25	=5.3+(0.58*(AM25-AK25)^.4)*(AM25-AK25)	=1.2*+AM25	=(AM25^.5)*AM25	=0.2*AM25	=0.25*0.2*($AM25*$AM25^.6)	=SUM(U25:AA25)
26	=5.3+(0.58*(AM26-AK26)^.4)*(AM26-AK26)	=1.2*+AM26	=(AM26^.5)*AM26	=0.2*AM26	=0.25*0.2*($AM26*$AM26^.6)	=SUM(U26:AA26)
27	=5.3+(0.58*(AM27-AK27)^.4)*(AM27-AK27)	=1.2*+AM27	=(AM27^.5)*AM27	=0.2*AM27	=0.25*0.2*($AM27*$AM27^.6)	=SUM(U27:AA27)
28	=5.3+(0.58*(AM28-AK28)^.4)*(AM28-AK28)	=1.2*+AM28	=(AM28^.5)*AM28	=0.2*AM28	=0.25*0.2*($AM28*$AM28^.6)	=SUM(U28:AA28)
29	=5.3+(0.58*(AM29-AK29)^.4)*(AM29-AK29)	=1.2*+AM29	=(AM29^.5)*AM29	=0.2*AM29	=0.25*0.2*($AM29*$AM29^.6)	=SUM(U29:AA29)
30	=5.3+(0.58*(AM30-AK30)^.4)*(AM30-AK30)	=1.2*+AM30	=(AM30^.5)*AM30	=0.2*AM30	=0.25*0.2*($AM30*$AM30^.6)	=SUM(U30:AA30)
31	=5.3+(0.58*(AM31-AK31)^.4)*(AM31-AK31)	=1.2*+AM31	=(AM31^.5)*AM31	=0.2*AM31	=0.25*0.2*($AM31*$AM31^.6)	=SUM(U31:AA31)
32	=5.3+(0.58*(AM32-AK32)^.4)*(AM32-AK32)	=1.2*+AM32	=(AM32^.5)*AM32	=0.2*AM32	=0.25*0.2*($AM32*$AM32^.6)	=SUM(U32:AA32)
33	=5.3+(0.58*(AM33-AK33)^.4)*(AM33-AK33)	=1.2*+AM33	=(AM33^.5)*AM33	=0.2*AM33	=0.25*0.2*($AM33*$AM33^.6)	=SUM(U33:AA33)
34	=5.3+(0.58*(AM34-AK34)^.4)*(AM34-AK34)	=1.2*+AM34	=(AM34^.5)*AM34	=0.2*AM34	=0.25*0.2*($AM34*$AM34^.6)	=SUM(U34:AA34)
35	=5.3+(0.58*(AM35-AK35)^.4)*(AM35-AK35)	=1.2*+AM35	=(AM35^.5)*AM35	=0.2*AM35	=0.25*0.2*($AM35*$AM35^.6)	=SUM(U35:AA35)
36	=5.3+(0.58*(AM36-AK36)^.4)*(AM36-AK36)	=1.2*+AM36	=(AM36^.5)*AM36	=0.2*AM36	=0.25*0.2*($AM36*$AM36^.6)	=SUM(U36:AA36)
37						
38	=SUM(W22:W36)	=SUM(X22:X36)	=SUM(Y22:Y36)	=SUM(Z22:Z	=SUM(AA22:AA36)	=SUM(U38:AA38)

	AD	AE	AF	AG	AH	AI	AJ	AK
12		=P3						
13	LCC	UNREL COST	TOTAL LCC		COST/FLT	$/lb AVE	AVE CAP	ETR FLIGHTS
14	=M14+S14+AB14	=$AE$38/AL$38*AM14	=AD14+AE14					
15	=M15+S15+AB15	=$AE$38/AL$38*AM15	=AD15+AE15					
16	=M16+S16+AB16	=$AE$38/AL$38*AM16	=AD16+AE16					
17	=M17+S17+AB17	=$AE$38/AL$38*AM17	=AD17+AE17					
18	=M18+S18+AB18	=$AE$38/AL$38*AM18	=AD18+AE18					
19	=M19+S19+AB19	=$AE$38/AL$38*AM19	=AD19+AE19					
20	=M20+S20+AB20	=$AE$38/AL$38*AM20	=AD20+AE20					
21	=M21+S21+AB21	=$AE$38/AL$38*AM21	=AD21+AE21					
22	=M22+S22+AB22	=$AE$38/AL$38*AM22	=AD22+AE22		=(S21+AB22)/AM22	=AH22/0.144	=((144*AK22+107.9*(AM22-AK22))/AM22)/1000	3
23	=M23+S23+AB23	=$AE$38/AL$38*AM23	=AD23+AE23		=(S22+AB23)/AM23	=AH23/0.144	=((144*AK23+107.9*(AM23-AK23))/AM23)/1000	8
24	=M24+S24+AB24	=$AE$38/AL$38*AM24	=AD24+AE24		=(S23+AB24)/AM24	=AH24/0.144	=((144*AK24+107.9*(AM24-AK24))/AM24)/1000	12
25	=M25+S25+AB25	=$AE$38/AL$38*AM25	=AD25+AE25		=(S24+AB25)/AM25	=AH25/0.144	=((144*AK25+107.9*(AM25-AK25))/AM25)/1000	12
26	=M26+S26+AB26	=$AE$38/AL$38*AM26	=AD26+AE26		=(S25+AB26)/AM26	=AH26/0.144	=((144*AK26+107.9*(AM26-AK26))/AM26)/1000	13
27	=M27+S27+AB27	=$AE$38/AL$38*AM27	=AD27+AE27		=(S26+AB27)/AM27	=AH27/0.144	=((144*AK27+107.9*(AM27-AK27))/AM27)/1000	13
28	=M28+S28+AB28	=$AE$38/AL$38*AM28	=AD28+AE28		=(S27+AB28)/AM28	=AH28/0.144	=((144*AK28+107.9*(AM28-AK28))/AM28)/1000	14
29	=M29+S29+AB29	=$AE$38/AL$38*AM29	=AD29+AE29		=(S28+AB29)/AM29	=AH29/0.144	=((144*AK29+107.9*(AM29-AK29))/AM29)/1000	14
30	=M30+S30+AB30	=$AE$38/AL$38*AM30	=AD30+AE30		=(S29+AB30)/AM30	=AH30/0.144	=((144*AK30+107.9*(AM30-AK30))/AM30)/1000	15
31	=M31+S31+AB31	=$AE$38/AL$38*AM31	=AD31+AE31		=(S30+AB31)/AM31	=AH31/0.144	=((144*AK31+107.9*(AM31-AK31))/AM31)/1000	15
32	=M32+S32+AB32	=$AE$38/AL$38*AM32	=AD32+AE32		=(S31+AB32)/AM32	=AH32/0.144	=((144*AK32+107.9*(AM32-AK32))/AM32)/1000	16
33	=M33+S33+AB33	=$AE$38/AL$38*AM33	=AD33+AE33		=(S32+AB33)/AM33	=AH33/0.144	=((144*AK33+107.9*(AM33-AK33))/AM33)/1000	16
34	=M34+S34+AB34	=$AE$38/AL$38*AM34	=AD34+AE34		=(S33+AB34)/AM34	=AH34/0.144	=((144*AK34+107.9*(AM34-AK34))/AM34)/1000	17
35	=M35+S35+AB35	=$AE$38/AL$38*AM35	=AD35+AE35		=(S34+AB35)/AM35	=AH35/0.144	=((144*AK35+107.9*(AM35-AK35))/AM35)/1000	17
36	=M36+S36+AB36	=$AE$38/AL$38*AM36	=AD36+AE36		=(S35+AB36)/AM36	=AH36/0.144	=((144*AK36+107.9*(AM36-AK36))/AM36)/1000	18
37	=SUM(AD14:AD36)							
38		=AA5/1000000+W5*AH	=AD37+AE38		=(S38+AB38)/AL36	=AH38/0.144	=((144*AK38+107.9*(AM38-AK38))/AM38)/100	=SUM(AK22:AK

	AL	AM	A	AQ	AR	AS	AT	AU	AV	AW
12				TOTAL COSTS WITH O						OPS+PROD
13	TOTAL FLT	FLT RATE		TOT INV	PROD	OPS	UNREL		TOT COST	COST/FLT
14				=M14*1.3	=S14*1.2	=AB14*1.2	=AE14		=SUM(AQ14:AT14)	
15				=M15*1.3	=S15*1.2	=AB15*1.2	=AE15		=SUM(AQ15:AT15)	
16				=M16*1.3	=S16*1.2	=AB16*1.2	=AE16		=SUM(AQ16:AT16)	
17				=M17*1.3	=S17*1.2	=AB17*1.2	=AE17		=SUM(AQ17:AT17)	
18				=M18*1.3	=S18*1.2	=AB18*1.2	=AE18		=SUM(AQ18:AT18)	
19				=M19*1.3	=S19*1.2	=AB19*1.2	=AE19		=SUM(AQ19:AT19)	
20				=M20*1.3	=S20*1.2	=AB20*1.2	=AE20		=SUM(AQ20:AT20)	
21				=M21*1.3	=S21*1.2	=AB21*1.2	=AE21		=SUM(AQ21:AT21)	
22	4	4		=M22*1.3	=S22*1.2	=AB22*1.2	=AE22		=SUM(AQ22:AT22)	=(S21+AB22)/AM22*1.2
23	16	=AL23-AM22		=M23*1.3	=S23*1.2	=AB23*1.2	=AE23		=SUM(AQ23:AT23)	=(S22+AB23)/AM23*1.2
24	36	=AL24-AL23		=M24*1.3	=S24*1.2	=AB24*1.2	=AE24		=SUM(AQ24:AT24)	=(S23+AB24)/AM24*1.2
25	56	=AL25-AL24		=M25*1.3	=S25*1.2	=AB25*1.2	=AE25		=SUM(AQ25:AT25)	=(S24+AB25)/AM25*1.2
26	77	=AL26-AL25		=M26*1.3	=S26*1.2	=AB26*1.2	=AE26		=SUM(AQ26:AT26)	=(S25+AB26)/AM26*1.2
27	99	=AL27-AL26		=M27*1.3	=S27*1.2	=AB27*1.2	=AE27		=SUM(AQ27:AT27)	=(S26+AB27)/AM27*1.2
28	122	=AL28-AL27		=M28*1.3	=S28*1.2	=AB28*1.2	=AE28		=SUM(AQ28:AT28)	=(S27+AB28)/AM28*1.2
29	146	=AL29-AL28		=M29*1.3	=S29*1.2	=AB29*1.2	=AE29		=SUM(AQ29:AT29)	=(S28+AB29)/AM29*1.2
30	171	=AL30-AL29		=M30*1.3	=S30*1.2	=AB30*1.2	=AE30		=SUM(AQ30:AT30)	=(S29+AB30)/AM30*1.2
31	196	=AL31-AL30		=M31*1.3	=S31*1.2	=AB31*1.2	=AE31		=SUM(AQ31:AT31)	=(S30+AB31)/AM31*1.2
32	222	=AL32-AL31		=M32*1.3	=S32*1.2	=AB32*1.2	=AE32		=SUM(AQ32:AT32)	=(S31+AB32)/AM32*1.2
33	249	=AL33-AL32		=M33*1.3	=S33*1.2	=AB33*1.2	=AE33		=SUM(AQ33:AT33)	=(S32+AB33)/AM33*1.2
34	277	=AL34-AL33		=M34*1.3	=S34*1.2	=AB34*1.2	=AE34		=SUM(AQ34:AT34)	=(S33+AB34)/AM34*1.2
35	306	=AL35-AL34		=M35*1.3	=S35*1.2	=AB35*1.2	=AE35		=SUM(AQ35:AT35)	=(S34+AB35)/AM35*1.2
36	336	=AL36-AL35		=M36*1.3	=S36*1.2	=AB36*1.2	=AE36		=SUM(AQ36:AT36)	=(S35+AB36)/AM36*1.2
37										
38	336	336		=M38*1.3	=S38*1.2+AQ38	=AB38*1.2+AR38	=AE38+AS38		=SUM(AV14:AV36)	=(S38+AB38)/AM38*1.2

	AX	AY	AZ	BA	BB	BC	BD	BE	BF
12				TOTAL LCC/YR	TOTAL LCC	TOTAL LCC	CUM TOT LCC	TOT AVE LCC	TOT AVE LCC
13	$/lb				COST/FLT	COST/LB		COST/FLT	COST/LB
14		1988		=AV14	=IF(AM14=0,0,BA14/AM14)	=BB14/0.144	=BA14	=IF(AL14=0,0,BD14/AL14)	=BE14/0.144
15		1989		=AV15	=IF(AM15=0,0,BA15/AM15)	=BB15/0.144	=BA15+BD14	=IF(AL15=0,0,BD15/AL15)	=BE15/0.144
16		=AY15+1		=AV16	=IF(AM16=0,0,BA16/AM16)	=BB16/0.144	=BA16+BD15	=IF(AL16=0,0,BD16/AL16)	=BE16/0.144
17		=AY16+1		=AV17	=IF(AM17=0,0,BA17/AM17)	=BB17/0.144	=BA17+BD16	=IF(AL17=0,0,BD17/AL17)	=BE17/0.144
18		=AY17+1		=AV18	=IF(AM18=0,0,BA18/AM18)	=BB18/0.144	=BA18+BD17	=IF(AL18=0,0,BD18/AL18)	=BE18/0.144
19		=AY18+1		=AV19	=IF(AM19=0,0,BA19/AM19)	=BB19/0.144	=BA19+BD18	=IF(AL19=0,0,BD19/AL19)	=BE19/0.144
20		=AY19+1		=AV20	=IF(AM20=0,0,BA20/AM20)	=BB20/0.144	=BA20+BD19	=IF(AL20=0,0,BD20/AL20)	=BE20/0.144
21		=AY20+1		=AV21	=IF(AM21=0,0,BA21/AM21)	=BB21/0.144	=BA21+BD20	=IF(AL21=0,0,BD21/AL21)	=BE21/0.144
22	=AW22/AJ22	=AY21+1		=AV22	=IF(AM22=0,0,BA22/AM22)	=BB22/0.144	=BA22+BD21	=IF(AL22=0,0,BD22/AL22)	=BE22/0.144
23	=AW23/AJ23	=AY22+1		=AV23	=IF(AM23=0,0,BA23/AM23)	=BB23/0.144	=BA23+BD22	=IF(AL23=0,0,BD23/AL23)	=BE23/0.144
24	=AW24/AJ24	=AY23+1		=AV24	=IF(AM24=0,0,BA24/AM24)	=BB24/0.144	=BA24+BD23	=IF(AL24=0,0,BD24/AL24)	=BE24/0.144
25	=AW25/AJ25	=AY24+1		=AV25	=IF(AM25=0,0,BA25/AM25)	=BB25/0.144	=BA25+BD24	=IF(AL25=0,0,BD25/AL25)	=BE25/0.144
26	=AW26/AJ26	=AY25+1		=AV26	=IF(AM26=0,0,BA26/AM26)	=BB26/0.144	=BA26+BD25	=IF(AL26=0,0,BD26/AL26)	=BE26/0.144
27	=AW27/AJ27	=AY26+1		=AV27	=IF(AM27=0,0,BA27/AM27)	=BB27/0.144	=BA27+BD26	=IF(AL27=0,0,BD27/AL27)	=BE27/0.144
28	=AW28/AJ28	=AY27+1		=AV28	=IF(AM28=0,0,BA28/AM28)	=BB28/0.144	=BA28+BD27	=IF(AL28=0,0,BD28/AL28)	=BE28/0.144
29	=AW29/AJ29	=AY28+1		=AV29	=IF(AM29=0,0,BA29/AM29)	=BB29/0.144	=BA29+BD28	=IF(AL29=0,0,BD29/AL29)	=BE29/0.144
30	=AW30/AJ30	=AY29+1		=AV30	=IF(AM30=0,0,BA30/AM30)	=BB30/0.144	=BA30+BD29	=IF(AL30=0,0,BD30/AL30)	=BE30/0.144
31	=AW31/AJ31	=AY30+1		=AV31	=IF(AM31=0,0,BA31/AM31)	=BB31/0.144	=BA31+BD30	=IF(AL31=0,0,BD31/AL31)	=BE31/0.144
32	=AW32/AJ32	=AY31+1		=AV32	=IF(AM32=0,0,BA32/AM32)	=BB32/0.144	=BA32+BD31	=IF(AL32=0,0,BD32/AL32)	=BE32/0.144
33	=AW33/AJ33	=AY32+1		=AV33	=IF(AM33=0,0,BA33/AM33)	=BB33/0.144	=BA33+BD32	=IF(AL33=0,0,BD33/AL33)	=BE33/0.144
34	=AW34/AJ34	=AY33+1		=AV34	=IF(AM34=0,0,BA34/AM34)	=BB34/0.144	=BA34+BD33	=IF(AL34=0,0,BD34/AL34)	=BE34/0.144
35	=AW35/AJ35	=AY34+1		=AV35	=IF(AM35=0,0,BA35/AM35)	=BB35/0.144	=BA35+BD34	=IF(AL35=0,0,BD35/AL35)	=BE35/0.144
36	=AW36/AJ36	=AY35+1		=AV36	=IF(AM36=0,0,BA36/AM36)	=BB36/0.144	=BA36+BD35	=IF(AL36=0,0,BD36/AL36)	=BE36/0.144
37									
38	=AW38/AJ38			=AV38	=AVERAGE(BB22:BB36)	=AVERAGE(BC22:BC36)			

	BH	BI	BJ	BK	BL	BM
12	DISCOUNT FACTOR		DISC OP COST	DIS OP COST	TOT LCC	TOT LCC
13	BASE YEAR = 1989		PER FLT ($M)	PER LB ($)	PER YEAR	PER FLT
14	1		=BH14*AW14	=IF(BJ14=0,0,BJ14/(AJ14))	=BA14*BH14	=BB14*BH14
15	=(1/(1+$AA$8))*BH14		=BH15*AW15	=IF(BJ15=0,0,BJ15/(AJ15))	=BA15*BH15	=BB15*BH15
16	=(1/(1+$AA$8))*BH15		=BH16*AW16	=IF(BJ16=0,0,BJ16/(AJ16))	=BA16*BH16	=BB16*BH16
17	=(1/(1+$AA$8))*BH16		=BH17*AW17	=IF(BJ17=0,0,BJ17/(AJ17))	=BA17*BH17	=BB17*BH17
18	=(1/(1+$AA$8))*BH17		=BH18*AW18	=IF(BJ18=0,0,BJ18/(AJ18))	=BA18*BH18	=BB18*BH18
19	=(1/(1+$AA$8))*BH18		=BH19*AW19	=IF(BJ19=0,0,BJ19/(AJ19))	=BA19*BH19	=BB19*BH19
20	=(1/(1+$AA$8))*BH19		=BH20*AW20	=IF(BJ20=0,0,BJ20/(AJ20))	=BA20*BH20	=BB20*BH20
21	=(1/(1+$AA$8))*BH20		=BH21*AW21	=IF(BJ21=0,0,BJ21/(AJ21))	=BA21*BH21	=BB21*BH21
22	=(1/(1+$AA$8))*BH21		=BH22*AW22	=IF(BJ22=0,0,BJ22/(AJ22))	=BA22*BH22	=BB22*BH22
23	=(1/(1+$AA$8))*BH22		=BH23*AW23	=IF(BJ23=0,0,BJ23/(AJ23))	=BA23*BH23	=BB23*BH23
24	=(1/(1+$AA$8))*BH23		=BH24*AW24	=IF(BJ24=0,0,BJ24/(AJ24))	=BA24*BH24	=BB24*BH24
25	=(1/(1+$AA$8))*BH24		=BH25*AW25	=IF(BJ25=0,0,BJ25/(AJ25))	=BA25*BH25	=BB25*BH25
26	=(1/(1+$AA$8))*BH25		=BH26*AW26	=IF(BJ26=0,0,BJ26/(AJ26))	=BA26*BH26	=BB26*BH26
27	=(1/(1+$AA$8))*BH26		=BH27*AW27	=IF(BJ27=0,0,BJ27/(AJ27))	=BA27*BH27	=BB27*BH27
28	=(1/(1+$AA$8))*BH27		=BH28*AW28	=IF(BJ28=0,0,BJ28/(AJ28))	=BA28*BH28	=BB28*BH28
29	=(1/(1+$AA$8))*BH28		=BH29*AW29	=IF(BJ29=0,0,BJ29/(AJ29))	=BA29*BH29	=BB29*BH29
30	=(1/(1+$AA$8))*BH29		=BH30*AW30	=IF(BJ30=0,0,BJ30/(AJ30))	=BA30*BH30	=BB30*BH30
31	=(1/(1+$AA$8))*BH30		=BH31*AW31	=IF(BJ31=0,0,BJ31/(AJ31))	=BA31*BH31	=BB31*BH31
32	=(1/(1+$AA$8))*BH31		=BH32*AW32	=IF(BJ32=0,0,BJ32/(AJ32))	=BA32*BH32	=BB32*BH32
33	=(1/(1+$AA$8))*BH32		=BH33*AW33	=IF(BJ33=0,0,BJ33/(AJ33))	=BA33*BH33	=BB33*BH33
34	=(1/(1+$AA$8))*BH33		=BH34*AW34	=IF(BJ34=0,0,BJ34/(AJ34))	=BA34*BH34	=BB34*BH34
35	=(1/(1+$AA$8))*BH34		=BH35*AW35	=IF(BJ35=0,0,BJ35/(AJ35))	=BA35*BH35	=BB35*BH35
36	=(1/(1+$AA$8))*BH35		=BH36*AW36	=IF(BJ36=0,0,BJ36/(AJ36))	=BA36*BH36	=BB36*BH36
37						
38		TO	=SUM(BJ22:BJ36)	=AVERAGE(BK22:BK36)	=AVERAGE(BL14:BL36)	=AVERAGE(BM22:BM36)

Appendix B. Listing of STARFLEET Stochastic Mission Model Output

The section contains a printout of the stochastic model as it appears to the user on the computer screen. The output reflects the effect of the input data and would change significantly if that data were changed. The printout was made using the Print function and by highlighting appropriate areas of the spreadsheet to define the print area. The second printout shows the formulas in spreadsheet format for the individual cells. The cells in the second formula printout correspond to the cells in the first printout.

	B	C	D	E	F	G	H	I	J	K
1										
2			PROJ FLTS	CUM FLTS	YRLY COST	CUM COST	PROJ $/LB	REVISED FLTS	CUM PROJ	CUM REVISED
3	YEAR	RN								
4	1993	0.40								
5	1994	0.02	4	4	325	325	564	4	4	4
6	1995	0.37	12	16	774	1099	477	6	16	10
7	1996	0.68	20	36	1223	2322	448	20	36	30
8	1997	0.56	20	56	1223	3545	440	20	56	50
9	1998	0.29	21	77	1279	4824	435	21	77	71
10	1999	0.70	22	99	1336	6160	432	22	99	93
11	2000	0.57	23	122	1392	7552	430	23	122	116
12	2001	0.84	24	146	1448	8999	428	24	146	140
13	2002	0.62	25	171	1504	10503	427	25	171	165
14	2003	0.44	25	196	1504	12007	425	25	196	190
15	2004	0.26	26	222	1560	13568	424	26	222	216
16	2005	0.95	27	249	1616	15184	423	26	249	242
17	2006	0.06	28	277	1672	16856	423	28	277	270
18	2007	0.69	29	306	1729	18585	422	14	306	284
19	2008	0.60	30	336	1785	20370	421	30	336	314
20										
21	TOT		336					314		
22										
23										
24		PROJFLTS	ACT FLT AVE	ACT FLT SD	PROJ $/LB	AVE COST/LB	SD COST/LB			
25	YEAR									
26	1993									
27	1994	4	3.70	0.48	$564	$615.69	83.86			
28	1995	12	10.70	3.83	$477	$692.79	625.93			
29	1996	20	19.20	3.36	$448	$514.72	182.98			
30	1997	20	18.10	6.38	$440	$559.39	358.84			
31	1998	21	19.80	3.48	$435	$508.01	212.74			
32	1999	22	20.60	7.57	$432	$474.10	93.61			
33	2000	23	22.40	4.60	$430	$459.51	59.81			
34	2001	24	19.90	10.80	$428	$461.16	46.99			
35	2002	25	18.00	11.37	$427	$464.85	42.48			
36	2003	25	23.80	10.40	$425	$462.16	40.25			
37	2004	26	25.30	11.04	$424	$458.21	32.66			
38	2005	27	19.30	14.73	$423	$465.79	45.19			
39	2006	28	25.30	8.47	$423	$461.51	42.51			
40	2007	29	22.50	15.95	$422	$462.30	32.75			
41	2008	30	24.00	15.60	$421	$461.95	31.64			
42										
43	TOTALS	336	293	8.54	$421	$462	$31.64			

	L	M	N	O	P	Q	R	S	T	U	V	W	X
1													
2	BACKLOG	SURGE CAP	DISASTER	DELAYS	ACT FLTS	CUM ACT FLTS		DELAY COST	DISASTER CO	OPER COST	CUM COST	ACT FLTS	COST/LB
3										$M	$M		
4													
5	0	1	0	0	2	2		0	0	212	212	2	$737
6	2	4	0	0	14	16		0	0	886	1,099	14	$477
7	0	6	0	0	20	36		0	0	1,223	2,322	20	$448
8	0	0	0	1	19	55		50	0	1,167	3,539	19	$447
9	1	7	0	0	22	77		0	0	1,336	4,874	22	$440
10	0	7	0	0	22	99		0	0	1,336	6,210	22	$436
11	0	7	0	0	23	122		0	0	1,392	7,602	23	$433
12	0	8	0	0	24	146		0	0	1,448	9,049	24	$430
13	0	8	0	0	25	171		0	0	1,504	10,553	25	$429
14	0	8	0	0	25	196		0	0	1,504	12,057	25	$427
15	0	8	0	0	26	222		0	0	1,560	13,618	26	$426
16	0	9	0	0	27	249		0	0	1,616	15,234	27	$425
17	0	9	0	0	28	277		0	0	1,672	16,906	28	$424
18	0	9	0	0	29	306		0	0	1,729	18,635	29	$423
19	0	0	0	1	29	335		10	0	1,729	20,374	29	$422
20													

	B	C	D	E	F	G	H
1							
2	.		PROJ FLTS	CUM FLTS	YRLY COST	CUM COST	PROJ $/LB
3	YEAR	RN					
4	1993	=RAND()					
5	=B4+1	=RAND()	4	=D5+E4	=(D5*390*144000+100000000)/1000000	=F5+G4	=G5/144000*1000000/E5
6	=B5+1	=RAND()	12	=D6+E5	=(D6*390*144000+100000000)/1000000	=F6+G5	=G6/144000*1000000/E6
7	=B6+1	=RAND()	20	=D7+E6	=(D7*390*144000+100000000)/1000000	=F7+G6	=G7/144000*1000000/E7
8	=B7+1	=RAND()	20	=D8+E7	=(D8*390*144000+100000000)/1000000	=F8+G7	=G8/144000*1000000/E8
9	=B8+1	=RAND()	21	=D9+E8	=(D9*390*144000+100000000)/1000000	=F9+G8	=G9/144000*1000000/E9
10	=B9+1	=RAND()	22	=D10+E9	=(D10*390*144000+100000000)/1000000	=F10+G9	=G10/144000*1000000/E10
11	=B10+1	=RAND()	23	=D11+E10	=(D11*390*144000+100000000)/1000000	=F11+G10	=G11/144000*1000000/E11
12	=B11+1	=RAND()	24	=D12+E11	=(D12*390*144000+100000000)/1000000	=F12+G11	=G12/144000*1000000/E12
13	=B12+1	=RAND()	25	=D13+E12	=(D13*390*144000+100000000)/1000000	=F13+G12	=G13/144000*1000000/E13
14	=B13+1	=RAND()	25	=D14+E13	=(D14*390*144000+100000000)/1000000	=F14+G13	=G14/144000*1000000/E14
15	=B14+1	=RAND()	26	=D15+E14	=(D15*390*144000+100000000)/1000000	=F15+G14	=G15/144000*1000000/E15
16	=B15+1	=RAND()	27	=D16+E15	=(D16*390*144000+100000000)/1000000	=F16+G15	=G16/144000*1000000/E16
17	=B16+1	=RAND()	28	=D17+E16	=(D17*390*144000+100000000)/1000000	=F17+G16	=G17/144000*1000000/E17
18	=B17+1	=RAND()	29	=D18+E17	=(D18*390*144000+100000000)/1000000	=F18+G17	=G18/144000*1000000/E18
19	=B18+1	=RAND()	30	=D19+E18	=(D19*390*144000+100000000)/1000000	=F19+G18	=G19/144000*1000000/E19
20							
21	TOT		=SUM(D4:D19)				
22							
23							
24		PROJ FLTS	ACT FLT AVE	ACT FLT SD	PROJ $/LB	AVE COST/LB	SD COST/LB
25	YEAR						
26	1993						
27	=B26+1	4	=AG27	=AH27	=H5	=AI27	=AJ27
28	=B27+1	12	=AG28	=AH28	=H6	=AI28	=AJ28
29	=B28+1	20	=AG29	=AH29	=H7	=AI29	=AJ29
30	=B29+1	20	=AG30	=AH30	=H8	=AI30	=AJ30
31	=B30+1	21	=AG31	=AH31	=H9	=AI31	=AJ31
32	=B31+1	22	=AG32	=AH32	=H10	=AI32	=AJ32
33	=B32+1	23	=AG33	=AH33	=H11	=AI33	=AJ33
34	=B33+1	24	=AG34	=AH34	=H12	=AI34	=AJ34
35	=B34+1	25	=AG35	=AH35	=H13	=AI35	=AJ35
36	=B35+1	25	=AG36	=AH36	=H14	=AI36	=AJ36
37	=B36+1	26	=AG37	=AH37	=H15	=AI37	=AJ37
38	=B37+1	27	=AG38	=AH38	=H16	=AI38	=AJ38
39	=B38+1	28	=AG39	=AH39	=H17	=AI39	=AJ39
40	=B39+1	29	=AG40	=AH40	=H18	=AI40	=AJ40
41	=B40+1	30	=AG41	=AH41	=H19	=AI41	=AJ41
42							
43	TOTALS	=SUM(C27:C	=SUM(D27:D41)	=AVERAGE(E27:E41)	=F41	=G41	=H41

	I	J	K	L	M	N
2	REVISED FLTS	CUM PROJ	CUM REVISED	BACKLOG	SURGE CAP	DISASTER
3						
4						
5	=IF(N4=1,INT(D5/2),IF(O5=1,D5-1,D5))	=D5	=I5	=IF(D4-P4>0,D4-P4,0)	=IF(C5<0.1,0,IF(C5>0.85,0,INT(D5/3)))	=IF(D5=0,0,IF(C5<0.1,1,0))
6	=IF(N5=1,INT(D6/2),IF(O6=1,D6-1,D6))	=D6+J5	=I6+K5	=IF(J5-Q5>0,J5-Q5,0)	=IF(C6<0.1,0,IF(C6>0.85,0,INT(D6/3)))	=IF(D6=0,0,IF(C6<0.1,1,0))
7	=IF(N6=1,INT(D7/2),IF(O7=1,D7-1,D7))	=D7+J6	=I7+K6	=IF(J6-Q6>0,J6-Q6,0)	=IF(C7<0.1,0,IF(C7>0.85,0,INT(D7/3)))	=IF(D7=0,0,IF(C7<0.1,1,0))
8	=IF(N7=1,INT(D8/2),IF(O8=1,D8-1,D8))	=D8+J7	=I8+K7	=IF(J7-Q7>0,J7-Q7,0)	=IF(C8<0.1,0,IF(C8>0.85,0,INT(D8/3)))	=IF(D8=0,0,IF(C8<0.1,1,0))
9	=IF(N8=1,INT(D9/2),IF(O9=1,D9-1,D9))	=D9+J8	=I9+K8	=IF(J8-Q8>0,J8-Q8,0)	=IF(C9<0.1,0,IF(C9>0.85,0,INT(D9/3)))	=IF(D9=0,0,IF(C9<0.1,1,0))
10	=IF(N9=1,INT(D10/2),IF(O10=1,D10-1,D10))	=D10+J9	=I10+K9	=IF(J9-Q9>0,J9-Q9,0)	=IF(C10<0.1,0,IF(C10>0.85,0,INT(D10/3)))	=IF(D10=0,0,IF(C10<0.1,1,0))
11	=IF(N10=1,INT(D11/2),IF(O11=1,D11-1,D11))	=D11+J10	=I11+K10	=IF(J10-Q10>0,J10-Q10,0)	=IF(C11<0.1,0,IF(C11>0.85,0,INT(D11/3)))	=IF(D11=0,0,IF(C11<0.1,1,0))
12	=IF(N11=1,INT(D12/2),IF(O12=1,D12-1,D12))	=D12+J11	=I12+K11	=IF(J11-Q11>0,J11-Q11,0)	=IF(C12<0.1,0,IF(C12>0.85,0,INT(D12/3)))	=IF(D12=0,0,IF(C12<0.1,1,0))
13	=IF(N12=1,INT(D13/2),IF(O13=1,D13-1,D13))	=D13+J12	=I13+K12	=IF(J12-Q12>0,J12-Q12,0)	=IF(C13<0.1,0,IF(C13>0.85,0,INT(D13/3)))	=IF(D13=0,0,IF(C13<0.1,1,0))
14	=IF(N13=1,INT(D14/2),IF(O14=1,D14-1,D14))	=D14+J13	=I14+K13	=IF(J13-Q13>0,J13-Q13,0)	=IF(C14<0.1,0,IF(C14>0.85,0,INT(D14/3)))	=IF(D14=0,0,IF(C14<0.1,1,0))
15	=IF(N14=1,INT(D15/2),IF(O15=1,D15-1,D15))	=D15+J14	=I15+K14	=IF(J14-Q14>0,J14-Q14,0)	=IF(C15<0.1,0,IF(C15>0.85,0,INT(D15/3)))	=IF(D15=0,0,IF(C15<0.1,1,0))
16	=IF(N15=1,INT(D16/2),IF(O16=1,D16-1,D16))	=D16+J15	=I16+K15	=IF(J15-Q15>0,J15-Q15,0)	=IF(C16<0.1,0,IF(C16>0.85,0,INT(D16/3)))	=IF(D16=0,0,IF(C16<0.1,1,0))
17	=IF(N16=1,INT(D17/2),IF(O17=1,D17-1,D17))	=D17+J16	=I17+K16	=IF(J16-Q16>0,J16-Q16,0)	=IF(C17<0.1,0,IF(C17>0.85,0,INT(D17/3)))	=IF(D17=0,0,IF(C17<0.1,1,0))
18	=IF(N17=1,INT(D18/2),IF(O18=1,D18-1,D18))	=D18+J17	=I18+K17	=IF(J17-Q17>0,J17-Q17,0)	=IF(C18<0.1,0,IF(C18>0.85,0,INT(D18/3)))	=IF(D18=0,0,IF(C18<0.1,1,0))
19	=IF(N18=1,INT(D19/2),IF(O19=1,D19-1,D19))	=D19+J18	=I19+K18	=IF(J18-Q18>0,J18-Q18,0)	=IF(C19<0.1,0,IF(C19>0.85,0,INT(D19/3)))	=IF(D19=0,0,IF(C19<0.1,1,0))

	O	P	Q		S
2	DELAYS	ACT FLTS	CUM ACT FLTS		DELAY COST
3					
4					
5	=IF(D5=0,0,IF(C5>0.85,1,0))	=IF(D5=0,0,IF(C5<0.1,0,IF(C4<0.1,INT(D5/2),IF(C5>0.85,D5-1,IF(M5>L5,L5+I5,I5+M5)))))	=P5+Q4		=O5*50
6	=IF(D6=0,0,IF(C6>0.85,1,0))	=IF(D6=0,0,IF(C6<0.1,0,IF(C5<0.1,INT(D6/2),IF(C6>0.85,D6-1,IF(M6>L6,L6+I6,I6+M6)))))	=P6+Q5		=O6*50
7	=IF(D7=0,0,IF(C7>0.85,1,0))	=IF(D7=0,0,IF(C7<0.1,0,IF(C6<0.1,INT(D7/2),IF(C7>0.85,D7-1,IF(M7>L7,L7+I7,I7+M7)))))	=P7+Q6		=O7*50
8	=IF(D8=0,0,IF(C8>0.85,1,0))	=IF(D8=0,0,IF(C8<0.1,0,IF(C7<0.1,INT(D8/2),IF(C8>0.85,D8-1,IF(M8>L8,L8+I8,I8+M8)))))	=P8+Q7		=O8*50
9	=IF(D9=0,0,IF(C9>0.85,1,0))	=IF(D9=0,0,IF(C9<0.1,0,IF(C8<0.1,INT(D9/2),IF(C9>0.85,D9-1,IF(M9>L9,L9+I9,I9+M9)))))	=P9+Q8		=O9*50
10	=IF(D10=0,0,IF(C10>0.85,1,0))	=IF(D10=0,0,IF(C10<0.1,0,IF(C9<0.1,INT(D10/2),IF(C10>0.85,D10-1,IF(M10>L10,L10+I10,I10+M10)))))	=P10+Q9		=O10*25
11	=IF(D11=0,0,IF(C11>0.85,1,0))	=IF(D11=0,0,IF(C11<0.1,0,IF(C10<0.1,INT(D11/2),IF(C11>0.85,D11-1,IF(M11>L11,L11+I11,I11+M11)))))	=P11+Q10		=O11*25
12	=IF(D12=0,0,IF(C12>0.85,1,0))	=IF(D12=0,0,IF(C12<0.1,0,IF(C11<0.1,INT(D12/2),IF(C12>0.85,D12-1,IF(M12>L12,L12+I12,I12+M12)))))	=P12+Q11		=O12*25
13	=IF(D13=0,0,IF(C13>0.85,1,0))	=IF(D13=0,0,IF(C13<0.1,0,IF(C12<0.1,INT(D13/2),IF(C13>0.85,D13-1,IF(M13>L13,L13+I13,I13+M13)))))	=P13+Q12		=O13*25
14	=IF(D14=0,0,IF(C14>0.85,1,0))	=IF(D14=0,0,IF(C14<0.1,0,IF(C13<0.1,INT(D14/2),IF(C14>0.85,D14-1,IF(M14>L14,L14+I14,I14+M14)))))	=P14+Q13		=O14*25
15	=IF(D15=0,0,IF(C15>0.85,1,0))	=IF(D15=0,0,IF(C15<0.1,0,IF(C14<0.1,INT(D15/2),IF(C15>0.85,D15-1,IF(M15>L15,L15+I15,I15+M15)))))	=P15+Q14		=O15*10
16	=IF(D16=0,0,IF(C16>0.85,1,0))	=IF(D16=0,0,IF(C16<0.1,0,IF(C15<0.1,INT(D16/2),IF(C16>0.85,D16-1,IF(M16>L16,L16+I16,I16+M16)))))	=P16+Q15		=O16*10
17	=IF(D17=0,0,IF(C17>0.85,1,0))	=IF(D17=0,0,IF(C17<0.1,0,IF(C16<0.1,INT(D17/2),IF(C17>0.85,D17-1,IF(M17>L17,L17+I17,I17+M17)))))	=P17+Q16		=O17*10
18	=IF(D18=0,0,IF(C18>0.85,1,0))	=IF(D18=0,0,IF(C18<0.1,0,IF(C17<0.1,INT(D18/2),IF(C18>0.85,D18-1,IF(M18>L18,L18+I18,I18+M18)))))	=P18+Q17		=O18*10
19	=IF(D19=0,0,IF(C19>0.85,1,0))	=IF(D19=0,0,IF(C19<0.1,0,IF(C18<0.1,INT(D19/2),IF(C19>0.85,D19-1,IF(M19>L19,L19+I19,I19+M19)))))	=P19+Q18		=O19*10

	T	U	V	W	X
2	DISASTER COST	OPER COST	CUM COST	ACT FLTS	COST/LB
3		$M	$M		
4					
5	=N5*1000	=P5*390*144000/1000000+100	=SUM(S5:U5)	=P5	=IF(Q5=0,390,V5/Q5/144000*1000000)
6	=N6*1000	=P6*390*144000/1000000+100	=SUM(S6:U6)+V5	=P6	=V6/Q6/144000*1000000
7	=N7*1000	=P7*390*144000/1000000+100	=SUM(S7:U7)+V6	=P7	=V7/Q7/144000*1000000
8	=N8*1000	=P8*390*144000/1000000+100	=SUM(S8:U8)+V7	=P8	=V8/Q8/144000*1000000
9	=N9*1000	=P9*390*144000/1000000+100	=SUM(S9:U9)+V8	=P9	=V9/Q9/144000*1000000
10	=N10*750	=P10*390*144000/1000000+100	=SUM(S10:U10)+V9	=P10	=V10/Q10/144000*1000000
11	=N11*750	=P11*390*144000/1000000+100	=SUM(S11:U11)+V10	=P11	=V11/Q11/144000*1000000
12	=N12*750	=P12*390*144000/1000000+100	=SUM(S12:U12)+V11	=P12	=V12/Q12/144000*1000000
13	=N13*750	=P13*390*144000/1000000+100	=SUM(S13:U13)+V12	=P13	=V13/Q13/144000*1000000
14	=N14*750	=P14*390*144000/1000000+100	=SUM(S14:U14)+V13	=P14	=V14/Q14/144000*1000000
15	=N15*750	=P15*390*144000/1000000+100	=SUM(S15:U15)+V14	=P15	=V15/Q15/144000*1000000
16	=N16*750	=P16*390*144000/1000000+100	=SUM(S16:U16)+V15	=P16	=V16/Q16/144000*1000000
17	=N17*750	=P17*390*144000/1000000+100	=SUM(S17:U17)+V16	=P17	=V17/Q17/144000*1000000
18	=N18*750	=P18*390*144000/1000000+100	=SUM(S18:U18)+V17	=P18	=V18/Q18/144000*1000000
19	=N19*750	=P19*390*144000/1000000+100	=SUM(S19:U19)+V18	=P19	=V19/Q19/144000*1000000

Appendix C. Listing of STARFLEET Infrastructure Model Output

The section contains a printout of the Infrastructure model as it appears to the user on the computer screen. The output reflects the effect of the input data and would change significantly if that data were changed. The printout was made using the Print function and by highlighting appropriate areas of the spreadsheet to define the print area. The second printout shows the formulas in spreadsheet format for the individual cells. The cells in the second printout correspond with the cells in the first printout.

	A	B	C	D	E	F	G	H	I
1	PRODUCTION		INPUT PARAMETERS						
2		RATE/DAY	# TRNSP BAT	TRNSP DAYS	# TRNSP VEH	INIT @ PROD	INIT @ INT	STOR @ PROD	STOR @ INTE
3	CORE ENGINES	1	8	1	2	0	0	40	40
4	CORE STRUCT	0.05	1	1	1	0	0	3	5
5	CORE AVION	0.05	2	1	1	0	0	3	5
6	BSTR ENGINES	0.2	8	1	2	0	0	50	50
7	BSTR STRUCT	0.2	2	1	1	0	0	3	5
8	BSTR AVION	0.2	4	1	1	0	0	3	5
9	PYLD INTEG	0.05	2	1	1	0	0	3	5
10	FAIRINGS	0.05	1	1	1	0	0	3	5
11	HYDROGEN	45,000	N/A	N/A	N/A	0	0	1,000,000	N/A
12									
13									
14	INTEGRATION								
15		PROC DAYS	# TRNSP BAT	TRNSP DAYS	# TRNSP VEH	INIT @ INTEG	INIT @ LNCH	STOR @ INTEG	
16	CORE	25	2	16	1	0	0		
17	BOOSTER	15	12	12	1	0	0		
18	VEHICLE	4	1	12	2	0	0	5	
19	PAYLOAD	5	1	6	2	0	0	1	
20	HYDROGEN	N/A	350000	4	1	0	0	N/A	
21	VEH INTEG	4							
22	PAYLD INTEG	5							
23									
24	LAUNCH SITE			VEHICLE PARAMETERS			LAUNCH SITE STORAGE		
25		PROC DAYS							
26	PRE-LAUNCH	6.5		ENGINES/COR	4		NEW BSTR STOR @ LNCH SI		10
27	LAUNCH	2		H2 PER ENG	150,000		REFB BSTR STOR @ LNCH SI		6
28	RECOV/REFURB	12					PAYLOAD STOR @ LNCH SIT		1
29				BSTR/VEH	4		H2 STOR @ LNCH SITE		6,000,000
30	# YRS OF OPS	5		ENG/BSTR	1				
31	OPS DAYS/YR	250		BSTR LIFE	20				
32	#OF PROD DAYS	1250		ENG RCV/FLT	4				
33				H2 PER ENG	140,000				
34									
35	OUTPUT RESULTS								
36									
37	# OF YEARS		5						
38	# OF PRODUCTION DAYS		1250				BOTTLENECKS		
39							CORE ENG TRANSP		0
40	PRODUCTION						CORE STUCT TRANSP		0
41		TOT #PROD	TOT #SHIPPED	TOT #INTEG	STATUS		CORE AVIONICS TRANSP		0
42	CORE ENGINES	1250	1250	248	EXCESS		BSTR ENG TRANSP		0
43	CORE STRUCT	62	62	62	CRITICAL		BSTR STRUCT TRANSP		0
44	CORE AVIONICS	62	62	62	CRITICAL		BSTR AVIONICS TRANSP		0
45	BSTR ENGINES	250	250	248	CRITICAL		PLATFORM TRANSP		0
46	BSTR STRUCT	250	250	248	CRITICAL		FAIRING TRANSP		0
47	BSTR AVIONICS	250	250	248	CRITICAL		HYDROGEN TRANSP		1,650,000
48	PLATFORM	62	62	62	CRITICAL				
49	FAIRING	62	62	62	CRITICAL		CORE ENG DEL TO INTEG		1002
50	HYDROGEN	56,250,000	54,600,000	N/A	CRITICAL		CORE STRUCT DEL TO INTEG		0
51							CORE AVIONICS DEL TO INT		0
52	INTEGRATION						BSTR ENG DEL TO INTEG		2
53		TOT #PROD	TOT #TRANSP	TOT #LAUNCH			BSTR STRUCT DEL TO INTEG		2
54	VEHICLES	62	62	62			BSTR AVIONICS DEL TO INT		2
55	PAYLOADS	62	62	62			PLATFORM DEL TO INTEG		0
56	HYDROGEN	56,250,000	54,600,000	71,920,000			FAIRING DEL TO INTEG		0
57									
58		6					VEH TRANS		0
59		NUMBER	COST				PAYLOAD TRANS		0
60	BSTRS RECOV	248	$1,240,000,000						
61	TOT BSTRs LAUNCHE	248	$620,000,000				VEH DEL TO PAD		0
62	TOT BSTRS CONSUME	12	$60,000,000				PAYLOAD DEL TO PAD		0
63	TOT BSTR ENG CONSU	12	$42,000,000				HYDROGEN DEL TO PAD		350,000
64	TOT CORES CONSUME	62	$1,246,200,000						
65	TOT CORE ENG CONSU	248	$843,200,000						
66									
67	TOT PAYLOAD TO ORB	8,928,000							
68	YEARLY PYLD TO ORB	1,785,600							
69	SHUTTLE EQUIV PYLD	162							
70	SHUTTLE EQUIV COST	$12,150,000,000							

	K	L	M	N	O	P
1	PRODUCTION			TRANSPORTATION		DEL TO INTEG
2						
3	CORE ENG PROD		BOTTLENECK	CORE ENG TRANSP		
4	ENGINE PROD RATE	1	0	TRNSPT BATCH SIZE	8	BOTTLENECK
5	INIT ENG PROD	0		TRNSPT TIME TO INTEG	1	1002
6	ENG STOR CAP	40		# OF TRNSPT AVAIL	2	
7	MAX # OF ENG SHIPMENTS	1250		MAX # OF SHIPMENTS	1250	
8	MAX # ENG STORED AT PR	8		TOT # OF SHIPPED	1250	
9	TOT ENGINES PRODUCE	1250				
10						
11	CORE STRUCT PROD		BOTTLENECK	CORE STRUCT TRANSP		BOTTLENECK
12	STRC PROD RATE	0.05	0	TRNSPT BATCH SIZE	1	0
13	INIT STRC PROD	0		TRNSPT TIME TO INTEG	1	
14	STRC STOR CAP	3		# OF TRNSPT AVAIL	1	
15	MAX # STRUCT SHIPMENTS	625		MAX # OF SHIPMENTS	625	
16	MAX # STRC STOR @ PROD	1		TOT # OF SHIPPED	62	
17	TOT STRUCTS PRODUCE	62				
18						
19	CORE AVION PROD		BOTTLENECK	CORE AVION TRANSP		BOTTLENECK
20	AVION PROD RATE	0.05	0	TRNSPT BATCH SIZE	2	0
21	INIT AVION PROD	0		TRNSPT TIME TO INTEG	1	
22	AVION STOR CAP	3		# OF TRNSPT AVAIL	1	
23	MAX # OF AVIONICS SHIP	625		MAX # OF SHIPMENTS	625	
24	MAX # AVION STOR @ PRO	2		TOT # OF SHIPPED	62	
25	TOT AVIONICS PROD	62				
26						
27	BSTR ENG PROD		BOTTLENECK	BSTR ENG TRANSP		BOTTLENECK
28	BSTR PROD RATE	0.2	0	TRNSPT BATCH SIZE	8	2
29	INIT BSTR PROD	0		TRNSPT TIME TO INTEG	1	
30	BSTR STOR CAP	50		# OF TRNSPT AVAIL	2	
31	MAX # OF BSTR SHIPMENTS	1250		MAX # OF SHIPMENTS	1250	
32	MAX # BSTR STOR @ PROD	8		TOT # OF SHIPPED	250	
33	TOT BSTRS PRODUCED	250				
34						
35	BSTR STRUCT PROD		BOTTLENECK	BSTR STRUCT TRANSP		BOTTLENECK
36	STRC PROD RATE	0.2	0	TRNSPT BATCH SIZE	2	2
37	INIT STRC PROD	0		TRNSPT TIME TO INTEG	1	
38	STRC STOR CAP	3		# OF TRNSPT AVAIL	1	
39	MAX # STRUCT SHIPMENTS	625		MAX # OF SHIPMENTS	625	
40	MAX # STRC STOR @ PROD	2		TOT # OF SHIPPED	250	
41	TOT STRUCTS PRODUCE	250				
42						
43	BSTR AVION PROD		BOTTLENECK	BSTR AVION TRANSP		BOTTLENECK
44	AVION PROD RATE	0.2	0	TRNSPT BATCH SIZE	4	2
45	INIT AVION PROD	0		TRNSPT TIME TO INTEG	1	
46	AVION STOR CAP	3		# OF TRNSPT AVAIL	1	
47	MAX # OF AVIONICS SHIP	625		MAX # OF SHIPMENTS	625	
48	MAX # AVION STOR @ PRO	4		TOT # OF SHIPPED	250	
49	TOT AVIONICS PROD	250				
50						
51	PLATFORM PRODUCTION		BOTTLENECK	PLATFORM TRANSP		BOTTLENECK
52	PLATFORM PROD RATE	0.05	0	TRNSPT BATCH SIZE	2	0
53	INIT PLATFORM PROD	0		TRNSPT TIME TO INTEG	1	
54	PLATFORM STOR CAP	3		# OF TRNSPT AVAIL	1	
55	MAX # PLATFORM SHIP	625		MAX # OF SHIPMENTS	625	
56	MAX # PLAT STOR @ PROD	2		TOT # OF SHIPPED	62	
57	TOT PLTFMS PRODUCED	62				
58						
59	FAIRING PRODUCTION		BOTTLENECK	FAIRING TRANSP		BOTTLENECK
60	FAIRING PROD RATE	0	0	TRNSPT BATCH SIZE	1	0
61	INIT FAIRING PROD	0		TRNSPT TIME TO INTEG	1	
62	FAIRING STOR CAP	3		# OF TRNSPT AVAIL	1	
63	MAX # OF FAIRING SHIP	625		MAX # OF SHIPMENTS	625	
64	MAX # FAIR STOR @ PROD	1		TOT # OF SHIPPED	62	
65	TOT FAIR'GS PRODUCED	62				
66						
67	HYDROGEN PRODUCTION		BOTTLENECK			
68	HYDROGEN PROD RATE	45,000	1,650,000			
69	INIT HYDROGEN PROD	0				
70	HYDROGEN STOR CAP	1,000,000				
71	MAX # HYDROGEN SHIP	156				
72	MAX # H2 STORED @ PROD	1,650,000				
73	TOT H2 PRODUCED	56,250,000				

	Q	R	S	T	U	V
1	BOOSTER INTEGRATION			VEHICLE INTEGRATON		
2						
3	CORE ENGINES			BSTR/CORE/AV/STRCT TIME	4	BOTTLENECK
4	INITIAL # AT INTEG	0		INIT # OF VEH @ INTEG	0	0
5	STOR CAP AT INTEG	40		VEH STOR CAP AT INTEG	5	
6	MAX # STORED	1002		MAX # VEH STORED	1	
7	TOTAL INTEGRATED	248		MAX#RAW MATERIAL VEH	62	
8				MAX#POSS BASED ON INTEG TIM	312	
9				TOT # VEH PRODUCED	62	
10						
11	CORE STRUCTURES					
12	INITIAL # AT INTEG	0				
13	STOR CAP AT INTEG	5				
14	MAX # STORED	4				
15	TOTAL INTEGRATED	62				
16						
17						
18						
19	CORE AVIONICS					
20	INITIAL # AT INTEG	0				
21	STOR CAP AT INTEG	5				
22	MAX # STORED	2				
23	TOTAL INTEGRATED	62				
24						
25						
26						
27	BOOSTER ENGINES					
28	INIT# AT INTEG	0				
29	STOR CAP AT INTEG	50				
30	MAX# STORED	8				
31	TOTAL INTEGRATED	248				
32						
33				PAYLOAD INTEGRATION		
34						
35	BOOSTER STRUCTURE			PYLD,PLAT,FAIR INTG TIME	5	BOTTLENECK
36	INIT# AT INTEG	0		INIT # OF PYLD AT INTEG	0	0
37	STOR CAP AT INTEG	5		PYLD STOR CAP AT INTEG	0	
38	MAX # STORED	4		MAX#PAY STORED AT INT	1	
39	TOTAL INTEGRATED	248		MAX#RAW MATERIAL PAYL	62	
40				MAX#POSS	250	
41				TOT#PYLD PRODUCED	62	
42						
43	BOOSTER AVIONICS					
44	INIT#AT INTEG	0				
45	STOR CAP AT INTEG	5				
46	MAX# STORED	4				
47	TOTAL INTEGRATED	248				
48						
49						
50						
51	PLATFORM					
52	INIT#AT INTEG	0				
53	STOR CAP AT INTEG	5				
54	MAX # STORED	2				
55	TOTAL INTEGRATED	62				
56						
57						
58						
59	FAIRING					
60	INIT # AT INTEG	0				
61	STOR CAP AT INTEG	5				
62	MAX # STORED	1				
63	TOTAL INTEGRATED	62				

	W	X	Y	Z	AA	AB	AC
1	VEHICLE TRANSPORT			PRE-LAUNCH		LAUNCH	
2							
3	VEH BATCH SIZE TO LCH S	1	BOTTLENECK	LAUNCH PREP	65		
4	TRANSPORT TIME TO SITE	12	0	ACTIVITY TIME	2		
5	#VEH TRANSP AVAIL	2					
6	MAX#VEH SHIPMENTS	104		INIT VEH AT SITE	0	BSTR REQ'D BASED ON PAYLDS	16
7	TOT# TRANSP TO SITE	62		NEW VEH STOR CAPACITY	10	BSTR REQ'D BASED ON VEHICLES	16
8				MAX VEH STORED AT SITE	1		
9				TOT BSTRs LAUNCHED	248	#LCHS BASED ON H2 AVAIL	91
10				TOT EXP BSTRS CONSUMED	12	#OF POSS LAUNCHES (DAYS)	147
11				TOT EXP BSTR ENG CONSUMD	12	TOTAL #OF LAUNCHES	62
12				TOT EXP BSTR RECOVERED	248		
13				TOT BSTRS CONSUMED	12		
14				TOT BSTR ENG CONSUMED	12		
15				TOT CORES CONSUMED	62		
16				TOT CORE ENG CONSUMD	248		
17							
18							
19							
20							
21							
22							
23							
24							
25							
26							
27							
28							
29							
30							
31							
32							
33	PAYLOAD TRANSPORT						
34							
35	PYLD BATCH SIZE TO L.SIT	1	BOTTLENECK				
36	TRANSP TIME TO L.SITE	6	0				
37	#OF PYLD TRANSP AVAIL	2					
38	MAX#PYLD TO L.SITE	208		INIT#PYLDS @ LAUNCH SITE	0		
39	TOT#PYLDS TRSP @SIT	62		PYLD STOR CAP @ LCH SITE	1		
40				MAX#PYLD STOR @ LCH SIT	1		
41				TOT#PYLD LAUNCHED	62		
42							
43							
44							
45							
46							
47							
48							
49							
50	HYDROGEN TRANSPORT					BOOSTER REFURB	
51							
52	H2 TRANSP BATCH SIZE	350,000	EXCESS PROD			REF BSTR STOR AT SITE	6
53	TRANSP TIME TO LNCH SIT	4	350,000			REC/REF ACTIVITY TIME	12
54	# OF H2 TRANSP AVAIL	1				#OF RECOVERY TRANSP	1
55	MAX # OF H2 SHIPMENTS	156		INIT#H2@LAUNCH SITE	0	TOT#BSTR RECOVERIES	248
56	TOT H2 TRSP @ SITE	54,600,000		H2 STOR CAP@LAUNCH SITE	6,000,000		
57				MAX H2 STOR@LAUNCH SITE	1,160,000		
58				TOT H2 CONSUMED	71,920,000		

	A	B	C	D
1	PRODUCTION		INPUT PARAMETERS	
2		RATE/DAY	# TRNSP BAT	TRNSP DAYS
3	CORE ENGINES	0.2	8	1
4	CORE STRUCT	0.05	1	1
5	CORE AVION	0.05	2	1
6	BSTR ENGINES	0.2	8	1
7	BSTR STRUCT	0.2	2	1
8	BSTR AVION	0.2	4	1
9	PYLD INTEG	0.06	2	1
10	FAIRINGS	0.05	1	1
11	HYDROGEN	45000	N/A	N/A
12				
13				
14	INTEGRATION			
15		PROC DAYS	# TRNSP BAT	TRNSP DAYS
16	CORE	25	2	16
17	BOOSTER	15	12	12
18	VEHICLE	4	1	12
19	PAYLOAD	5	1	6
20	HYDROGEN	N/A	350000	4
21	VEH INTEG	4		
22	PAYLD INTEG	5		
23				
24	LAUNCH SITE			VEHICLE PARAMETERS
25		PROC DAYS		
26	PRE-LAUNCH	6.5		ENGINES/CORE
27	LAUNCH	2		H2 PER ENG
28	RECOV/REFURB	12		
29				BSTR/VEH
30	# YRS OF OPS	5		ENG/BSTR
31	OPS DAYS/YR	250		BSTR LIFE
32	#OF PROD DAYS	=B30*B31		ENG RCV/FLT
33				H2 PER ENG
34				
35	OUTPUT RESULTS			
36				
37	# OF YEARS		=B30	
38	# OF PRODUCTION D		=B32	
39				
40	PRODUCTION			
41		TOT#PROD	TOT#SHIPPED	TOT#INTEG
42	CORE ENGINES	=L9	=O8	=R7
43	CORE STRUCT	=L17	=O16	=R15
44	CORE AVIONICS	=L25	=O24	=R23
45	BSTR ENGINES	=L33	=O32	=R31
46	BSTR STRUCT	=L41	=O40	=R39
47	BSTR AVIONICS	=L49	=O48	=R47
48	PLATFORM	=L57	=O56	=R55
49	FAIRING	=L65	=O64	=R63
50	HYDROGEN	=L73	=X56	N/A
51				
52	INTEGRATION			
53		TOT#PROD	TOT#TRANSP	TOT#LAUNCH
54	VEHICLES	=U9	=X7	=AC11
55	PAYLOADS	=U41	=X39	=AA41
56	HYDROGEN	=L73	=X56	=AA58
57				
58		6		
59		NUMBER	COST	
60	BSTRS RECOV	=AC55	=B60*5000000	
61	TOT BSTRs LAUNCHED	=AA9	=124*5000000	
62	TOT BSTRS CONSUMED	=AA13	=5000000*B62	
63	TOT BSTR ENG CONSUM	=AA14	=3500000*B63	
64	TOT CORES CONSUMED	=AA15	=3400000*4*B64+B64*6500000	
65	TOT CORE ENG CONSUM	=AA16	=3400000*B65	
66				
67	TOT PAYLOAD TO ORBI	=AC11*144000		
68	YEARLY PYLD TO ORBI	=B67/B30		
69	SHUTTLE EQUIV PYLDS	=INT(B67/55000)		
70	SHUTTLE EQUIV COST	=B69*75000000		

	E	F	G	H	I
1					
2	# TRNSP VEH	INIT @ PROD	INIT @ INIT	STOR @ PROD	STOR @ INTEG
3	2	0	0	40	40
4	1	0	0	3	5
5	1	0	0	3	5
6	2	0	0	50	50
7	1	0	0	3	5
8	1	0	0	3	5
9	1	0	0	3	5
10	1	0	0	3	5
11	N/A	0	0	1000000	N/A
12					
13					
14					
15	# TRNSP VEH	INIT @ INTEG	INIT @ LNCH	STOR @ INTEG	
16	1	0	0		
17	1	0	0		
18	2	0	0	5	
19	2	0	0	1	
20	1	0	0	N/A	
21					
22					
23					
24			LAUNCH SITE STORAGE		
25					
26	4		NEW BSTR STOR @ LNCH SITE		10
27	150000		REFB BSTR STOR @ LNCH SITE		6
28			PAYLOAD STOR @ LNCH SITE		1
29	4		H2 STOR @ LNCH SITE		6000000
30	1				
31	20				
32	3				
33	140000				
34					
35					
36					
37					
38			BOTTLENECKS		
39			CORE ENG TRANSP		=M4
40			CORE STUCT TRANSP		=M12
41	STATUS		CORE AVIONICS TRANSP		=M20
42	=IF(INT(B42/E26)<(D54+1),"CRITICAL","EXCESS")		BSTR ENG TRANSP		=M28
43	=IF(INT(B43)<(D55+1),"CRITICAL","EXCESS")		BSTR STRUCT TRANSP		=M36
44	=IF(INT(B44)<(D54+1),"CRITICAL","EXCESS")		BSTR AVIONICS TRANSP		=M44
45	=IF(INT(B45/(E30*E29))<(D54+1),"CRITICAL","EXCESS")		PLATFORM TRANSP		=M52
46	=IF(INT(B46/E29)<(D54+1),"CRITICAL","EXCESS")		FAIRING TRANSP		=M60
47	=IF(INT(B47/E29)<(D54+1),"CRITICAL","EXCESS")		HYDROGEN TRANSP		=M68
48	=IF(INT(B48)<(D54+1),"CRITICAL","EXCESS")				
49	=IF(INT(B49)<(D54+1),"CRITICAL","EXCESS")		CORE ENG DEL TO INTEG		=P5
50	=IF(INT(B50)<(D56+1),"CRITICAL","EXCESS")		CORE STRUCT DEL TO INTEG		=P12
51			CORE AVIONICS DEL TO INTEG		=P20
52			BSTR ENG DEL TO INTEG		=P28
53			BSTR STRUCT DEL TO INTEG		=P36
54			BSTR AVIONICS DEL TO INTEG		=P44
55			PLATFORM DEL TO INTEG		=P52
56			FAIRING DEL TO INTEG		=P60
57					
58			VEH TRANS		=V4
59			PAYLOAD TRANS		=V36
60					
61			VEH DEL TO PAD		=Y4
62			PAYLOAD DEL TO PAD		=Y36
63			HYDROGEN DEL TO PAD		=Y53

	K	L	M	N
1	PRODUCTION			TRANSPORTATION
2				
3	CORE ENG PROD		BOTTLENECK	CORE ENG TRANSP
4	ENGINE PROD RATE	=B3	=MAX(0,L9+F3-L7*C3)	TRNSPT BATCH SIZE
5	INIT ENG PROD	=F3		TRNSPT TIME TO INTEG
6	ENG STOR CAP	=H3		# OF TRNSPT AVAIL
7	MAX # OF ENG SHIPMENTS	=INT(B32/(2*D3/E3))		MAX # OF SHIPMENTS
8	MAX # ENG STORED AT PROD	=MAX(F3,C3,L9+F3-L7*C3)		TOT # OF SHIPPED
9	TOT ENGINES PRODUCED	=INT(L4*B32)		
10				
11	CORE STRUCT PROD		BOTTLENECK	CORE STRUCT TRANSP
12	STRC PROD RATE	=B4	=MAX(0,L17+F4-L15*C4)	TRNSPT BATCH SIZE
13	INIT STRC PROD	=F4		TRNSPT TIME TO INTEG
14	STRC STOR CAP	=H4		# OF TRNSPT AVAIL
15	MAX # STRUCT SHIPMENTS	=INT(B32/(2*D4/E4))		MAX # OF SHIPMENTS
16	MAX # STRC STOR @ PROD	=MAX(F4,C4,L17+F4-L15*C4)		TOT # OF SHIPPED
17	TOT STRUCTS PRODUCED	=INT(L12*B32)		
18				
19	CORE AVION PROD		BOTTLENECK	CORE AVION TRANSP
20	AVION PROD RATE	=B5	=MAX(0,L25+F5-L23*C5)	TRNSPT BATCH SIZE
21	INIT AVION PROD	=F5		TRNSPT TIME TO INTEG
22	AVION STOR CAP	=H5		# OF TRNSPT AVAIL
23	MAX # OF AVIONICS SHIP	=INT(B32/(2*D5/E5))		MAX # OF SHIPMENTS
24	MAX # AVION STOR @ PROD	=MAX(F5,C5,L25+F5-L23*C5)		TOT # OF SHIPPED
25	TOT AVIONICS PROD	=INT(L20*B32)		
26				
27	BSTR ENG PROD		BOTTLENECK	BSTR ENG TRANSP
28	BSTR PROD RATE	=B6	=MAX(0,L33+F6-L31*C6)	TRNSPT BATCH SIZE
29	INIT BSTR PROD	=F6		TRNSPT TIME TO INTEG
30	BSTR STOR CAP	=H6		# OF TRNSPT AVAIL
31	MAX # OF BSTR SHIPMENTS	=INT(B32/(2*D6/E6))		MAX # OF SHIPMENTS
32	MAX # BSTR STOR @ PROD	=MAX(F6,C6,L33+F6-L31*C6)		TOT # OF SHIPPED
33	TOT BSTRS PRODUCED	=INT(L28*B32)		
34				
35	BSTR STRUCT PROD		BOTTLENECK	BSTR STRUCT TRANSP
36	STRC PROD RATE	=B7	=MAX(0,L41+F7-L39*C7)	TRNSPT BATCH SIZE
37	INIT STRC PROD	=F7		TRNSPT TIME TO INTEG
38	STRC STOR CAP	=H7		# OF TRNSPT AVAIL
39	MAX # STRUCT SHIPMENTS	=INT(B32/(2*D7/E7))		MAX # OF SHIPMENTS
40	MAX # STRC STOR @ PROD	=MAX(F7,C7,L41+F7-L39*C7)		TOT # OF SHIPPED
41	TOT STRUCTS PRODUCED	=INT(L36*B32)		
42				
43	BSTR AVION PROD		BOTTLENECK	BSTR AVION TRANSP
44	AVION PROD RATE	=B8	=MAX(0,L49+F8-L47*C8)	TRNSPT BATCH SIZE
45	INIT AVION PROD	=F8		TRNSPT TIME TO INTEG
46	AVION STOR CAP	=H8		# OF TRNSPT AVAIL
47	MAX # OF AVIONICS SHIP	=INT(B32/(2*D8/E8))		MAX # OF SHIPMENTS
48	MAX # AVION STOR @ PROD	=MAX(F8,C8,L49+F8-L47*C8)		TOT # OF SHIPPED
49	TOT AVIONICS PROD	=INT(L44*B32)		
50				
51	PLATFORM PRODUCTION		BOTTLENECK	PLATFORM TRANSP
52	PLATFORM PROD RATE	=B9	=MAX(0,L57+F9-L55*C9)	TRNSPT BATCH SIZE
53	INIT PLATFORM PROD	=F9		TRNSPT TIME TO INTEG
54	PLATFORM STOR CAP	=H9		# OF TRNSPT AVAIL
55	MAX # PLATFORM SHIP	=INT(B32/(2*D9/E9))		MAX # OF SHIPMENTS
56	MAX # PLAT STOR @ PROD	=MAX(F9,C9,L57+F9-L55*C9)		TOT # OF SHIPPED
57	TOT PLTFMS PRODUCED	=INT(B32*L52)		
58				
59	FAIRING PRODUCTION		BOTTLENECK	FAIRING TRANSP
60	FAIRING PROD RATE	=B10	=MAX(0,L65+F10-L63*C10)	TRNSPT BATCH SIZE
61	INIT FAIRING PROD	=F10		TRNSPT TIME TO INTEG
62	FAIRING STOR CAP	=H10		# OF TRNSPT AVAIL
63	MAX # OF FAIRING SHIP	=INT(B32/(2*D10/E10))		MAX # OF SHIPMENTS
64	MAX # FAIR STOR @ PROD	=MAX(F10,C10,L65+F10-L63*C10)		TOT # OF SHIPPED
65	TOT FAIRGS PRODUCED	=INT(L60*B32)		
66				
67	HYDROGEN PRODUCTION		BOTTLENECK	
68	HYDROGEN PROD RATE	=B11	=MAX(0,L73+F11-L71*C20)	
69	INIT HYDROGEN PROD	=F11		
70	HYDROGEN STOR CAP	=H11		
71	MAX # HYDROGEN SHIP	=INT(B32/(2*D20/E20))		
72	MAX # H2 STORED @ PROD	=MAX(F11,C20,L73+F11-L71*C20)		
73	TOT H2 PRODUCED	=INT(L68*B32)		

	O	P	Q	R
1		REL TO INTEG	BOOSTER INTEGRATION	
2				
3			CORE ENGINES	
4	=C3	BOTTLENECK	INITIAL # AT INTEG	=G3
5	=D3	=MAX(0,O8+G3-R7)	STOR CAP AT INTEG	=I3
6	=E3		MAX # STORED	=MAX(R4,E26,C3,O8+R4-R7)
7	=L7		TOTAL INTEGRATED	=E26*U9
8	=MIN(O7*C3,L9+F3)			
9				
10				
11		BOTTLENECK	CORE STRUCTURES	
12	=C4	=MAX(0,O16+G4-R15)	INITIAL # AT INTEG	=G4
13	=D4		STOR CAP AT INTEG	=I4
14	=E4		MAX # STORED	=MAX(R12,E29,C4,O16+R12-R15)
15	=L15		TOTAL INTEGRATED	=U9
16	=MIN(O15*C4,L17+F4)			
17				
18				
19		BOTTLENECK	CORE AVIONICS	
20	=C5	=MAX(0,O24+G5-R23)	INITIAL # AT INTEG	=G5
21	=D5		STOR CAP AT INTEG	=I5
22	=E5		MAX # STORED	=MAX(R20,1,C5,O24+R20-R23)
23	=L23		TOTAL INTEGRATED	=U9
24	=MIN(O23*C5,L25+F5)			
25				
26				
27		BOTTLENECK	BOOSTER ENGINES	
28	=C6	=MAX(0,O32+G6-R31)	INIT# AT INTEG	=G6
29	=D6		STOR CAP AT INTEG	=I6
30	=E6		MAX# STORED	=MAX(R28,E30*E29,C6,O32+R28-R31)
31	=L31		TOTAL INTEGRATED	=U9*E29*E30
32	=MIN(O31*C6,L33+F6)			
33				
34				
35		BOTTLENECK	BOOSTER STRUCTURE	
36	=C7	=MAX(0,O40+G7-R39)	INIT# AT INTEG	=G7
37	=D7		STOR CAP AT INTEG	=I7
38	=E7		MAX # STORED	=MAX(R36,E29,C7,O40+R36-R39)
39	=L39		TOTAL INTEGRATED	=U9*E29
40	=MIN(O39*C7,L41+F7)			
41				
42				
43		BOTTLENECK	BOOSTER AVIONICS	
44	=C8	=MAX(0,O48+G8-R47)	INIT#AT INTEG	=G8
45	=D8		STOR CAP AT INTEG	=I8
46	=E8		MAX# STORED	=MAX(R44,E29,C8,O48+R44-R47)
47	=L47		TOTAL INTEGRATED	=U9*E29
48	=MIN(L47*C8,L49+F8)			
49				
50				
51		BOTTLENECK	PLATFORM	
52	=C9	=MAX(0,O56+G16-R55)	INIT#AT INTEG	=G9
53	=D9		STOR CAP AT INTEG	=I9
54	=E9		MAX # STORED	=MAX(R52,1,C9,O56+R60-R55)
55	=L55		TOTAL INTEGRATED	=U41
56	=MIN(O55*C9,L57+F9)			
57				
58				
59		BOTTLENECK	FAIRING	
60	=C10	=MAX(0,O64-R63+G10)	INIT # AT INTEG	=G10
61	=D10		STOR CAP AT INTEG	=I10
62	=E10		MAX # STORED	=MAX(R60,1,C10,O64+G10-R63)
63	=L63		TOTAL INTEGRATED	=U41
64	=MIN(O63*C10,L65+F10)			

	V	W	X	Y
1		VEHICLE TRANSPORT		
2				
3	BOTTLENECK	VEH BATCH SIZE TO LCH SITE	=C18	BOTTLENECK
4	=MAX(0,U9+F18-(X7*X3))	TRANSPORT TIME TO SITE	=D18	=MAX(0,X7+B18-AC11*(E29-E30)*E30)
5		#VEH TRANSP AVAIL	=E18	
6		MAX#VEH SHIPMENTS	=INT(B32/(2*D18/E18))	
7		TOT# TRANSP TO SITE	=MIN(U9+F18,X6*C18)	
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33		PAYLOAD TRANSPORT		
34				
35	BOTTLENECK	PYLD BATCH SIZE TO L.SITE	=C19	BOTTLENECK
36	=MAX(0,U41-(X39*C19))	TRANSP TIME TO L.SITE	=D19	=MAX(0,X39+G19-AC11)
37		#OF PYLD TRANSP AVAIL	=E19	
38		MAX#PYLD TO L.SITE	=INT((B32)/(2*D19/E19))	
39		TOT#PYLDS TRSP @SITE	=MIN(U41+F19,X38*D19)	
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50		HYDROGEN TRANSPORT		
51				
52		H2 TRANSP BATCH SIZE	=C20	EXCESS PROD
53		TRANSP TIME TO LNCH SITE	=D20	=MAX(0,C20,X56+G20-AA58)
54		# OF H2 TRANSP AVAIL	=E20	
55		MAX # OF H2 SHIPMENTS	=INT(B32/(2*D20/E20))	
56		TOT H2 TRSP @ SITE	=MIN(X55*C20,L73+F9)	

	Z	AA	AB
1	PRE-LAUNCH		LAUNCH
2			
3	LAUNCH PREP	=B26	
4	ACTIVITY TIME	=B27	
5			
6	INIT VEH AT SITE	=B18	BSTR REQ'D BASED ON PAYLDS
7	NEW VEH STOR CAPACITY	=I26	BSTR REQ'D BASED ON VEHICLES
8	MAX VEH STORED AT SITE	=MAX(B18,1,C18,X7+B18-AC11)	
9	TOT BSTRs LAUNCHED	=AC11*E29	#LCHS BASED ON H2 AVAIL
10	TOT EXP BSTRS CONSUMED	=INT(AC11/E31*E29)	#OF POSS LAUNCHES (DAYS)
11	TOT EXP BSTR ENG CONSUMD	=AA10*E30	TOTAL #OF LAUNCHES
12	TOT EXP BSTR RECOVERED	=AC11*E32	
13	TOT BSTRS CONSUMED	=INT(AA12*(AA10/AA9)+(AA9-AA12))	
14	TOT BSTR ENG CONSUMED	=E30*AA13	
15	TOT CORES CONSUMED	=AC11	
16	TOT CORE ENG CONSUMD	=AC11*E26	
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
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30			
31			
32			
33			
34			
35			
36			
37			
38	INIT#PYLDS @ LAUNCH SITE	=G19	
39	PYLD STOR CAP @ LCH SITE	=I28	
40	MAX#PYLD STOR @ LCH SIT	=MAX(G19,1,X39+G19-AC11)	
41	TOT#PYLD LAUNCHED	=AC11	
42			
43			
44			
45			
46			
47			
48			
49			
50			BOOSTER REFURB
51			
52			REF BSTR STOR AT SITE
53			REC/REF ACTIVITY TIME
54			#OF RECOVERY TRANSP
55	INIT#H2@LAUNCH SITE	=G20	TOT#BSTR RECOVERIES
56	H2 STOR CAP@LAUNCH SITE	=I29	
57	MAX H2 STOR@LAUNCH SITE	=MAX(G20,(E26*E27+E29*E30*E33),X52,X56+G20-AA58)	
58	TOT H2 CONSUMED	=INT(AC11*(E27*E26+E30*E29*E33))	

	AC
1	
2	
3	
4	
5	
6	=(E32*INT(((X39+B19)/E31)+1))
7	=E32*INT(((X7+B18)/E31)+1)
8	
9	=INT((X56+B20)/(E29*E27))
10	=INT(B32/(B26+B27))
11	=MIN(AC10,AC9,X39+B19,X7)
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
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42	
43	
44	
45	
46	
47	
48	
49	
50	
51	
52	=I27
53	=B28
54	=E20
55	=AC11*E32
56	
57	
58	

Appendix D. STARFLEET Equations

This section contains all of the key equations used in the STARFLEET models. They are presented using normal terminology with references to modules and cells in the particular STARFLEET model. Parameters not listed here are input constants.

Life Cycle Cost Model (Appendix A)

Input Parameters (A1-E15)

Rate input by user

$$\text{Factor} = \frac{\text{Log (Rate)}}{\text{Log (2)}}$$

Cost of Unreliability (A22-G38)

ETR Net Load = ETR Payload * ETR Load Factor
WTR Net Load = WTR Payload * WTR Load Factor
Number of Failures = (1-Rel Rate) * (ETR flts + WTR flts)
Years System Down = Number of Failures * Downtime Penalty
Number of Flts Missed = Years System Down * Flight Rate
Number of Flts Unflown = Number of Flts Missed * (1-Backlog Fraction)
Total Payload Unflown = Flts Unflown * Average Payload per Flight
Lost Value of Unflown Payload = Total Payload Unflown * Payload Cost per Lb
Downtime Cost = Years System Down * Downtime Cost Per Year
Payload Losses = Cost of Payload/Lb *Number of Failures * Average Payload
Total Losses = Payload Losses + Downtime Cost + Value of Unflown Payload

Research and Development (I12-N38)

Total Investment = Tech + Vehicle + Facilities + Non-recurring Production costs

Recurring Production (O12-S36)

Stage 1 Yrly Costs = Stg 1 Init Cost $* ((Y*Y^{lc}*Y^{pc})-((Y-1)(Y-1)^{lc}(Y-1)^{pc})$
Y is the current years cumulative flt rate
Y-1 is the previous years cumulative flt rate
lc is the learning curve factor
pc is the production curve factor
Stage 2 Yrly Cost = Stg 2 Init Cost * [same as above]
Shroud Yrly Cost = Shroud Init Cost * [same as above]
Project Mgmt Yrly Cost = Init Mgmt Cost $* ((Y*Y^{lc})$
Y is the current years flight rate
lc is the mgmt learning curve factor
Total Production Costs = Stg 1 + Stg 2 + Shroud + Mgmt costs

Operations (N2-U26)

ETR Ops = Input Fixed Cost + Init Cost * Yrly ETR Flt Rate $^{(1-lc)}$
lc is the ETR ops learning curve factor
WTR Ops = Input Fixed Cost + Init Cost * Yrly WTR Flt Rate $^{(1-lc)}$
lc is the WTR ops learning curve factor
Total Propellant = Total Yearly flight rate * input cost per flight
GSE Spares = Init Cost * Yearly Flt Rate $^{(1-lc)}$
lc is the spare learning curve factor
Training = Input Cost per Flt * Yearly Flight Rate
Project Mgmt = Init Cost * Yearly Flt Rate$^{(1-lc)}$
lc is the mgmt learning curve factor
Annual Ops Costs = Fac Maintenance + ETR Ops + WTR Ops + Tot Propellant
+ GSE Spares + Training + Proj Mgmt

Unreliability Costs (AE13-AE38)

Yrly Unreliability Costs = (Tot Unrel Losses + Number of Failures * Net Cost per Flt)
* Yearly Flt Rate / Total Flt Rate

Mission Model (AJ13-AJ39)

Ave Yrly Capacity = (ETR Capacity * ETR FLTS + WTR Capacity * WTR Flts)/Tot Flts

LCC Costs

(AD11-AD36)
LCC (Net Costs) = Tot Invest + Tot Prod + Tot Ops
(AF11-AF36)
Tot LCC = LCC + Unrel costs
(AH11-AH36)
Cost/Flt (Net) = (Yrly Ops + Yrly Prod Costs)/Yrly Flt Rate
(AI11-AI36)
$/Lb (Net) = [Cost/Flt (Net)] / 144,000

Total Costs With Overhead (AQ13-AS39)

Inv = Tot Investment * 1.3
Prod = Tot Prod * 1.2
Ops = Tot Ops * 1.2
Tot Cost = Tot Inv + Prod + Ops + Unrel
(AW11-AW39)
Cost/Flt = (Ops + Prod) / Yearly Flts
$/Lb = (Cost/Flt) / 144,000

Total LCC (BA11-BF39)

Total LCC = Tot Cost w/oh from above
Total LCC/Flt = Tot LCC/Yrly Flt Rate
Total LCC/Lb = (Tot LCC/Flt) / 144,000
Cum Tot LCC = Cumulative Sum of all Tot LCC

Cum Tot LCC/Flt = Cum Tot Lcc/Cum Tot Flts
Cum Tot LCC/Lb = (Cum Tot LCC/Flt)/144,000

Discounted LCC (BH11-BN39)

Yrly Discount Factor (DF) = $1/(1+i)^n$ where n is the number of years in the future and i is the assumed interest rate.
DLCC = LCC * DF
DLCC/Flt= TLCC/Flt * DF

Stochastic Mission Model (Appendix B)

Input and Calculations (A1-G39)

Rand Numb = Rand() This is an EXCEL function that provides a random number after every spreadsheet operation. It does not need a seed and does not repeat number strings unless a seed value is inserted.
Disaster Value = 1 if rand number is greater than user defined value, ie, Disaster = 1 if Rand() > .90
Value = 0 if random number is less than user defined value, ie Disaster = 0 if Rand() < .90
Delay Value = 1 or 0 same calculation as above
Revised Flt Rate Modified Flight rate based on delay and disaster penalties If disaster occurs in previous yr, current revised =*Proj Flt rate/2*

Act Flts = Actual flights is determined by a logical set of nested ifs and a user input set of projected flight rates:
If Rand() > Failure criteria Act Flts = 0
If Rand() < Delay criteria Act Flts = Revised - 1
If Previous Years Act Flts = 0 Act Flts = Rev Flt rate / 2
If Backlog > Surge Rate, Flt rate = Rev Flt rate + Surge rate
If Backlog < Surge Rate, Flt rate = Rev Flt rate + Backlog
Else Flt rate = Rev Flt rate
Backlog = Cumulative Revised Flt Rate - Cumulative Actual Flt Rate
Surge Capacity = Revised Flt Rate * Surge factor

Stochastic Costing Example (A44-G61)

Delay Cost = Delay flag * Delay cost factor
Disaster Cost = Disaster flag * Disaster cost factor
Oper Cost = Actual Flt Rate * input cost per flight + input Fixed Cost per year
Cumulative Cost = Cumulative sum of Oper Cost + Disaster Cost + Delay Cost
Cost/Lb = Cumulative Cost/(Cumulative Flts * 144,000)

Output Summary

Act Flight Average = Excel function Sum() that sums defined rows or columns
Act Flight SD = Actual Flight Standard Deviations Excel Function STDEV() that performs Std Dev calculation of specified data

STARFLEET Infrastructure Model (Appendix C)

Output Summary (A60-C70)

Tot Bstr Costs = Tot Bstrs * Bstr Unit Costs
Tot Core Costs = Tot Cores * Core Unit Costs
Tot Payload to Orbit = Total Launches * 144,000
Yearly Payload to Orbit = Tot Payload to Orbit/Yrs of Ops
Shuttle Equiv Payloads = Integer(Tot Launched * 144,000/55,000)
Shuttle Equiv Cost = Shuttle Equiv Payloads * Shuttle Cost per Payload ($75M)

Production (K1-L73)

Max Number of Engine Shipment = Integer(Tot # of Prod Days/(2 * Trans Days /# of Trans Veh)
Max Number of Engines Stored at Production = Maximum of [(Init # at Prod), (# in a Trans Batch), (# Prod + Init at Prod - Max# of Ship * Number per Shipment)]
Total Engines produced = Engine Production Rate * Tot Number of Prod Days

The remainder of the Production calculations for the other eight components are similar. All that changes is the initial input data contained in the input module.

Production Bottleneck (M3-M68)

This looks at the excess production over the available transportation capability.
Bottleneck = Maximum [0, (# Prod + Init at Prod - Max# of Ship * # per Shipment)]
All nine production bottlenecks are computed using the same equation with different inputs.

Transportation (N1-O65)

Maximum number of shipments = Integer(Tot # of Prod Days/(2 * Trans Days /# of Trans Veh)
Total Number Shipped = Minimum [(Init # at Prod + Tot# Prod), (Max# of Shipment * # per Shipment)]

These equations are used for all nine components with their respective inputs.

Bottleneck Delivery to Integration (P1-P60)

Bottleneck here refers to an excess of delivered and initial components at integrations compared to the total number integrated into launch vehicles.
Bottleneck = Maximum [0, (Init# at Integ + Tot# Shipped - Total Integrated)]
These equations are used for all components except Hydrogen.

Integration (Q1-R65)

Maximum * Stored at Integration = Maximum [Init at Integ, (*of Tran Veh * Number per Tran Batch), (Init at Integ + Tot Shipped - Tot * Integrate)]

Total Integrated = Number of Components per Vehicle * Tot * of Vehicles Produced

These calculations consider the components individually. These equations are used for all components except Hydrogen.

Vehicle/Payload Integration (T1-U41)

These equation calculate the total number of launch vehicles (Booster + Core) and Payloads.

Max Number of Vehicles Stored = Maximum [Init Veh at Integ, * in Trans Batch, (Tot Integ + Init at Integ - Tot Shipped to Launch Site)]

Max Raw Material Veh = Minimum Integer [(*Component Prod + Init Comp)/Comp per Veh -- for each component]
This includes Avionics, Structure and Engines for both the Booster and the Core.

Poss Number of Production Vehicles = Total Number of Prod Days/Integ Rate per Day

Total Number of Vehicles Produced = Minimum (Max Raw Mat Vehicles, Poss Prod Veh)

Payload Integration equations are similar to the above.

Bottleneck = Maximum [0, (Tot Integrated + Init at Integ -Tot Trans to Launch Site)]

Vehicle/Payload/Hydrogen Transport to Launch Site (W1-V35)

Max Number of Shipments = Tot Number of Ops Days/(2*Trans Time * Trans Veh)

Total Transp to Launch Site = Minimum [(Max*of Shipment * *per Shipment), (Tot * Integrated + Init * at Integ)]

Bottleneck = (0, Tot Transp to Site + Init at Site -Tot Used at Launch)

These equations are used for all three major components.

Pre-Launch (Z1-AA55)

Total Components Launched = Tot * of launches * Components per Vehicle

Tot Components Consumed = Integer(Tot Launches/Component Life)*Components per Veh + Tot Launches * * of Expendable Comp per Flt

Total Components Recovered = Total Flight Rate * * Recovered per Flight

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The product of this research effort was a simplified cost analysis tool that can be used to determine life-cycle-costs for the Advanced Launch System. The major objective was to develop a tool that would allow quick analysis of proposals and provide data input in a timely fashion. The work was co-sponsored by the Advanced Launch System program office and the Air Force Rocket Propulsion Laboratory.

This effort produced a core program that can be used to determine life-cycle-costs as a function of system components, production infrastructures, reliability assumptions and flexible mission models. The life cycle cost model can operate in either a deterministic or stochastic mode depending on user inputs. An additional effort modeled the production infrastructure using a network flow system. This system modeled the flow of the basic vehicle components from initial production through final launch.

The analysis tool utilizes a commercially available spreadsheet package available for most personal computers. The analyst using this program operates in a user-friendly environment that simplifies data input and problem formulation. The user has a wide variety of output formats and graphics options that simplify report generation.

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